Analysing the effects on the All-island electricity system in 2020 if Ireland increases policy support for heat pumps

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Abstract:

Under current European Union climate obligations Ireland has committed to producing 16% of gross final consumption from renewable sources in 2020. The target is split between three sectors; transport, heat and electricity. As with many other member states, Ireland's electricity sector is on a good trajectory to fulfilling the renewable requirements but the other two sectors are not so well positioned. This paper analyses the effects of using a holistic approach in an attempt to reach the targets. Integrating the electricity and heat sectors through heat pumps is the main focus of this paper. To successfully achieve this, barriers to technological change need to be identified, which in this paper is completed via a literature review. A theoretical concept and framework are this implemented to address barriers, thus lowering their influence over technological uptake. Using a consumer choice heat model to identify different levels of technological uptake and a complex PLEXOS model of the All-island electricity system, analysis is carried out to highlight any effects of additional demand on the electricity system from the increased number of heat pumps in the sector. This paper finds that integrating the two sectors offers at least three benefits: 1) Increased levels of renewable heat; 2) Non-ETS emissions are lowered, a necessary requirement under an EU policy decision; and 3) More renewable capacity is facilitated onto the electricity system.

Preface

This project report has been written by a student from the 4th semester of the master programme *"Sustainable Energy Planning and Management"* in the Department of Development and Planning at Aalborg University. It has been carried out in the period from 1st February 2014 to 4th June 2014. The theme of this semester is "Master Thesis" and the project report addresses this by conducting a case study and computational analysis, investigating the effects on Ireland's electricity system in 2020 if there was increased policy support for heat pumps using PLEXOS power market simulation software and two heat models. The project report has been written assuming the readers are on at least the same academic level as the author.

The Harvard method is used for references in the project report. References therefore consist of the surname of the author(s) and year of publication, e.g. [Unruh, 2002]. If there are more than two authors, the reference will consist of the surname of the first author and the paragraph "et al". References with the same author and year are separated alphabetically, e.g. [European Union, 2009a], [European Union, 2009b] etc. For references where it has not been possible to identify the date of publication the year it replaced with "n.d.", e.g. [Example, n.d.], and page numbers are added where needed.

A consumer choice heat model is used to create scenarios based on the uptake of heat pumps in Ireland's heat sector, then an excel model is used to change the heat and in turn electricity demands from an annual value into a hourly demand profile. PLEXOS is used to model the different electricity system scenarios and with microsoft excel, various graphs and visual representations of the PLEXOS output data are created.

Acknowledgements

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- Matthew Clancy from the Energy Modelling Group in SEAI for his cooperation and guidance during my time researching for this report, also for access to PLEXOS and SEAI's Consumer Choice Heat model.

Cover page picture: The Importance of Electricity [Finolex, 2014]

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1 Introduction

Heat pumps offer an alternative method of providing domestic, commercial and industrial heating that implies lower consumption of conventional oil and gas and instead relies upon electricity as the energy input. Under current climate obligations Ireland has committed to generating 12% of its gross final consumption from renewable heat. To achieve this target requires significant investment in the conversion of traditional heating systems to renewable alternatives. To date Ireland has focused upon achieving the necessary share of generation of electricity from renewable sources. However more effort in terms of policy support needs to be directed towards the heat sector if Ireland intends to meet all of its ambitions under the ambitious EU Climate and Energy Directive 2009/09/EC [European Union, 2009a]. This paper considers Ireland and the 27 other member states that have signed up to mandatory national targets under the EU Directive. The Directive was adopted into EU law in 2009 and consists of binding legislation to ensure that the EU reaches ambitious climate and energy targets by 2020. Three fundamental targets of the Directive are as follows: 20% reduction in greenhouse gas (GHG) emissions compared to 1990 levels; EU Gross Final Consumption (GFC) must be 20% sourced from renewable energy sources (RES); EU energy efficiency to improve by 20%.

The EU Decision 2009/406/EC was also adopted into EU law in 2009. This policy introduced a 2020 target to reduce the total EU non-Emission Trading System[1] GHG emissions by 20% compared to 2005 levels. Using heat pumps to electrifying the heat sector would move non-ETS emissions into traded emissions, helping to meet both the non-ETS and renewable heat targets at the same time. This transfer would have a significant effect on the non-ETS emissions sector as generating heat is responsible for the largest share. The subsequent effect on the trading emissions levels is expected to be offset by the rapidly increasing levels of RES-E generation required to meet RES-E targets. Both the EU Directive and Decision play a large role in the direction of this report and can be seen as motivation behind the analysis.

RES policy support across the European Union

In reaching the Directive targets, the percentage split of EU final energy consumption by sector has certain significance. Figure 1.1 illustrates the sectorial split in 2010 with the heating

[1] Non-ETS consists of emissions from residential, agriculture, small business/industry, public sector, and waste related[European Union, 2009b]. It excludes large industry and power generation.

(and cooling) sector accounting for 47% of the final energy consumed, the transport sector representing 32% and electricity sector with 21%[Sanner et al., 2013]. This could be seen as an indicator for how time, manpower, and other resources should be split to focus on each sector with equal intent on addressing and ultimately reaching the targets. In the EU, renewable policy support is in existence however the majority is based on generating renewable electricity (RES-E).

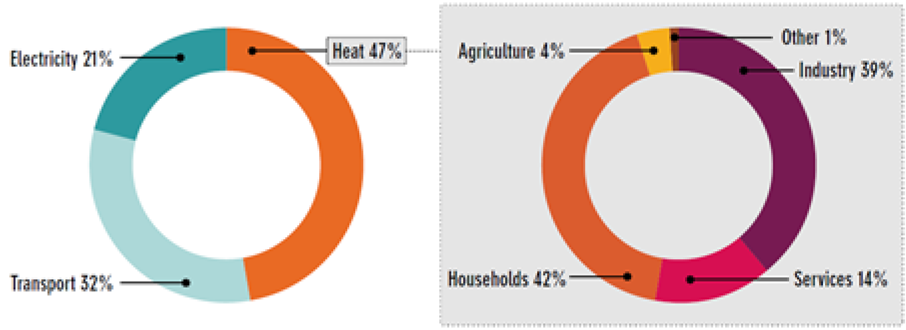

Figure 1.1: Final energy use in EU-27 by energy sector (left) and final energy use for heat sector (right) in 2010[Sanner et al., 2013]

A recent report compiled within the European research project 'RE-Shaping' analyses the progress of each member state in relation to fulfilling Directive targets. The report found certain shortcomings that were evident in many EU countries especially in relation to renewable heat (RES-H). For instance, only one in three member states have concrete plans for reaching their RES-H targets[Ragwitz et al., 2012]. Similarly, analysis carried out by the International Energy Agency (IEA) found that the heating sector is a neglected area in terms of energy policy and technology. The IEA report also suggests that decarbonising the heat sector is fundamental for a low-carbon energy system in the future[IEA, 2012].

The RE-Shaping report goes further to analyse the future perspectives of member states and more policy gaps were highlighted. It found that on the current trajectory the majority of member states will not reach their targets without some policy intervention to remove the barriers still affecting the levels of renewable uptake. The report also found that addressing non-economic barriers such as better spatial planning, shorter lead time on renewable projects and improving the overall planning process would increase the levels of renewable integration for all member states. The main difference occurred when national renewable policies were strengthened, implementing the necessary policy decisions to support the renewables in each of the three sectors: transport, electricity and heat.

1.1 Ireland's Renewable and Emissions Target Compliance

Ireland signed up to mandatory targets in the EU Directive to ensure 16% of GFC is produced by RES in 2020. This overall RES target is split into the three main sectors; transport, heating, and electricity. The RES target attributed to transport (RES-T) is 10%, for heating (RES-H) 12%, and for the electricity (RES-E) sector the target is 40%. Other 2020 targets such as the GHG emissions reduction, non-ETS emissions and energy efficiency reduction targets were all set at 20% for Ireland. The energy efficiency requirement will have a large part to play in achieving all the targets set out. Because targets are a percentage of the overall energy demand - lowering system demand means the RES absolute target value is also lowered, resulting in a RES share increase.

The Directive required a National Renewable Energy Action Plan (NREAP) and National Energy Efficiency Action Plan (NEEAP) to be published outlining various methods and approaches for each member state to meet the targets. These plans along with policy support mechanisms have been incorporated into Ireland's energy policy framework to deliver on the transport and electricity targets, however in terms of heat sector policy Ireland lags behind in a similar way to that outlined by the IEA and RE-Shaping reports. Ireland's national energy agency, the Sustainable Energy Authority of Ireland (SEAI) have suggested in their publication 'Energy Forecasts for Ireland to 2020' that Ireland can meet their renewable electricity target of 40%, however even in the most optimistic scenario (which assumes no further policy change) Ireland is not expected to reach their RES-H target[SEAI, 2013a]. To emphasise on this point further, figure 1.2 displays the level of RES-H contribution in EU member states in 2010 and their planned level of contribution in 2020. Countries such as Latvia, Estonia, and Finland all enjoy RES-H penetration above 38% in 2010, while Sweden approaches 60% making them the European leaders in RES-H. The countries with high market shares of RES-H have been obtained mainly through long term policy support for alternative energy sources but other factors such as the availability of biomass also have an effect.

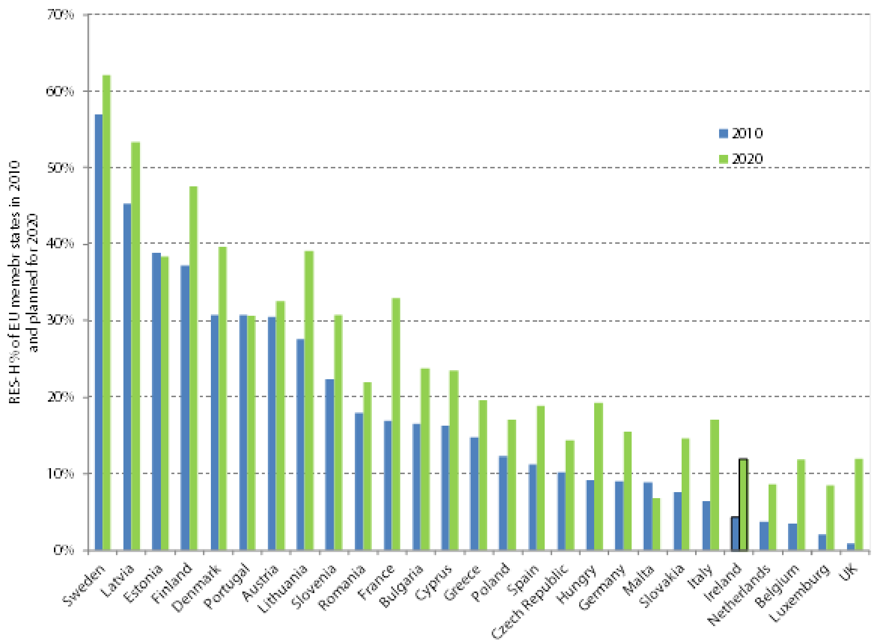

Figure 1.2: Contribution of RES-H to thermal consumption in 2010 and planned for 2020. (Sourced from member states NREAP's available from the EU transparency platform[European Union, 2014])

Regarding Ireland's non-ETS target there have been steps taken to meet the requirements, see NREAP or NEEAP for details. A recent example of a step towards reducing non-ETS emissions is the increased carbon tax on solid fuel introduced in May 2014[Revenue, 2014]. SEAI report that between 2005 – 2010 Ireland's non-ETS emissions reduced by 1.4% annually, from 2010 to 2012 the reduction was 7.1% annually, with another 5.4% fall in 2012. At the end of 2012 Ireland had reached the cusp of their 2020 non-ETS target at 22.2 million tonnes of CO_2 produced, only 0.35 million tonnes off the 2020 target of 21.85 million tonnes per annum[SEAI, 2013b]. The nation's economic downturn played a large part in the emission reductions. However as the target is intrinsically connected to economic growth there may still be a large issue if Ireland's economy experiences some degree of reinvigoration which would result in both industrial and transport related emissions increasing.[SEAI, 2013b]

RES policy support in Ireland

Indications from a SEAI report highlight considerable issues surrounding planning, policy and social acceptance that are integral to reaching the targets. It is presumed that the RES-E sector could reach the Directive target if the wind power capacity available under the Gate 3 grid connection process is installed[2]. The electricity sector benefits from the availability of the Renewable Energy Feed-In-Tariff (REFIT) policy which ensures a fixed price per unit of renewable electricity for the first 15 years of generation. Similarly in the transport sector, regulatory incentives[3] and policy measures for electric vehicles are utilised, although the expected uptake of electric vehicles is dependent on both technology development and rapid expansion of the liquid biofuel supply sector nationally and internationally[Clancy, 2014].

As previously mentioned, the heat sector represents a large share of final energy use on an EU scale but is neglected from a policy point of view. Although figure 1.2 shows that Ireland has a long way to go before it can achieve the RES-H target, this paper argues that Ireland can learn from the European leaders in the heat sector and be inspired from their vision and determination. Examples include Denmark's willingness to reduce import dependencies in the 1970's after the oil crisis or Sweden's early adoption of district heating using domestically sourced biomass fuels. Section 1.2 introduces the concept of integrating Ireland's heat and electricity sectors for an effective and opportunistic renewable solution to the issues Ireland may face in 2020.

1.2 Integrating Ireland's Heat and Electricity Sectors

Electricity is regarded by many as 'high grade energy' due to its characteristics of being easily transportable, clean, and can be renewably generated relatively easily. Ireland is one of the best placed countries in Europe to harness wind energy and for this reason plans are made to utilise this resource to achieve the majority of the RES targets[DCENR, 2010b]. Using the widespread

[2]Gate 3 is third round of connection offers from the system operators to perspective generators for connection to the All-island grid, see [EirGrid, 2013] for more details

[3]Currently all transport fuel in Ireland contains at least 3% biofuel. This is expected to rise to 10% by 2020

electricity transmission system for more than it is currently used for, could benefit many actors in macro-scale Ireland. For instance, studies suggest electricity systems would gain from more flexible technologies and capacity, this in turn would play a significant role in integrating more renewable capacity making the entire system more emission friendly[Hedegaard et al., 2012]. From a heat sector perspective, renewable heat can be regarded as being both difficult and expensive to produce and deliver. With high percentages of RES-E in 2020 there would be an opportunity to avail of this renewable source to the benefit of the heat sector while also facilitating more renewables into the electricity sector. In the case of heat pumps which is pertinent to this report, they are seen by some to be the ideal technology for integrating wind power into the energy system especially if they can be dispatchable[Hedegaard et al., 2012],[Biegel et al., 2014].

Integrating these two sectors would have another benefit of reallocating non-ETS emissions into traded emissions through increased electrification of the heat sector. Reducing non-ETS emissions is seen as a large issue in Ireland as the nation's agriculture sector is large with a significant national herd[Perez et al., 2004]. Ideas about where to lower non-ETS emissions is a constant source of debate and this concept could be a viable solution especially considering the updates from the EU that 2030 targets could be solely GHG based, not renewable based.

Concerns with additional demand primarily surround variability and lack of flexibility to safely and securely maintain a stable system. Another point to outline is the issue of timing or the profile of the extra demand which could add to the peak hour demand for electricity currently being experienced. In an electricity system that is relatively isolated with limited interconnection capacity to the nearest system such as Ireland's, the issue of stability is paramount.

1.3 Research Question

The primary research question of this paper is:

'What are the effects on the All-island electricity system if Ireland increases policy support for heat pumps in an attempt to fulfil their 2020 RES-H targets?'

At the current rate, Ireland is set to be non-compliant with the EU targets which will result in costly procurement of surplus RES-H compliance from other EU member states. A possible solution has been identified which consists of two phases that require completion before the feasibility of the proposal can be fully determined. Phase 1 is to identify the current and maximum uptake of heat pumps in Ireland. This uptake will have a large bearing over Ireland's ability to comply with the RES-H target as heat pumps have renewable status under the Directive. This paper will propose a policy support which would encourage uptake in the Irish market presented as Phase 1. This will be followed by a number of related sub-questions:

- What is the maximum level of heat pump uptake possible in Ireland up to 2020?
- What are the barriers that prevent and policy support mechanisms that support heat pump uptake?

The main focus of this report, contained in Phase 2, is to analyse how Ireland's 2020 electricity system will respond with the extra electricity demand that is unavoidable through completion of the phase 1. The extra demand will affect more than just generation output - capacity, reserve, and technological requirements for the entire system will also increase accordingly. Extra demand at peak hours could strain the system to its limit unless operational strategy is adjusted in time to renege any such incident. In any electricity system such as Ireland's that is geographically isolated and not highly interconnected (electrically), the issues incumbent with extra demand could show large ill-effects to the system. Coupled with the lack of interconnection, high percentages of variable renewable energy, limited storage capacity, extreme system demand variations and the ingredients for a system collapse are unmistakeable. The electricity system will be analysed to highlight any areas of concern, this will be followed with sensitivity analysis if necessary on various aspects of the operational strategies from both the heat and electricity sectors perspective.

1.4 Report Delimitation

All analysis carried out is based on the year 2020 and Ireland's ability to reach the EU mandated renewable targets set forth in the Directive. The Republic of Ireland is used as the central focus for a case study. The results from this case study suggest what could occur by 2020 in Ireland. They do not try to embody anything other than the parameters outlines thus far.

This report will analyse both the heat and electricity sectors in Ireland. The heat sector is a domestic market which is relatively small and diffuse. It is individualised through a large dispersion of household central heating systems. Ireland's electricity system is combined with Northern Ireland's and known as the All-island electricity system or from a market point of view, the Single Energy Market (SEM). In 2020 the SEM is expected to be operating without many transmission and generation constraints currently in situ due to the establishment of the system operator programmes such as Grid 25[Eirgrid, 2010b] and DS3[Eirgrid, 2011]. This system will be analysed as one large system with unfixed electricity flows to Great Britain's system. This case study and report will concentrate on increasing heat pump uptake in the heat sector and analysing the electricity sector only. All else is external to the scope of this report.

Thesis Perspective: Theory and Methodology 2

This chapter allows an insight into both the theoretical and methodological frameworks used to analyse the study content. Various aspects of the study that hinder technological change from occurring are discussed using a theoretical approach. Following this, the methodological approach used to analyse the study content is explained - outlining the research design and types of computational analyses used to analyse the study content.

2.1 Theoretical Framework

As alluded to in chapter 1, there is a resolve in Ireland to fulfil the 2020 targets set out by the European Union. While it is expected that the RES-E targets will be met (mainly through the expansion of the wind power capacity), the RES-H sector on the other hand is set to fall short in its attempt to reach the agreed target. With the 2020 deadline five years away, there still may be time to re-evaluate Ireland's stance and the nation's trajectory in relation to reaching their RES-H deliverables. Solutions are in existence however many of whom need some form of kick-start to trigger an increase in uptake. Whether the trigger originates from a specific pattern of timing and sequence of events, from political, institutional or organisational change or through technological advancement, it matters not. From a macro-scale view, each step taken towards the RES-H target also benefits Ireland's overall renewable energy commitments.

In recent decades Ireland's main heat source has been oil based, followed by natural gas. Oil represented 45% of the total final consumption (TFC) of thermal energy in 2012, followed by natural gas at 38% of the share. For a nation such as Ireland with an extremely high import dependency (85% in 2012) the question lingers – *'Why is Ireland so dependent on imported fossil fuels when alternatives energy sources (some of which are domestic) can be availed of?'*

Gregory C. Unruh explains in the article *'Escaping carbon lock-in'* that industrial economics have distorted the level playing field for technological change to occur, resulting in reduced consumer choice[Unruh, 2002]. The article has certain proximity with this report as it deals with a similar fossil fuel path dependency issue. Industrial economics act as a lock-in for the heat sector in Ireland through technological and institutional interaction with the market. This interaction over an extended period has paved the way for Ireland's dependency on fossil fuel based consumption, which can be referred to as a *Techno-Institutional Complex (TIC)* and links to the issue of *Choice Awareness*.

Techno-institutional complex

"The difficulty lies, not with the new ideas, but in escaping the old one." - John Maynard Keynes[1]

Analysis of Ireland's heat sector unearthed several self-reinforcing barriers that dissuade change, barriers that can be attributed to TIC. The purpose of such barriers are to obstruct or in some cases stop change even when the benefits of change over status quo are laid out bare. An example of a barrier in Ireland's case can be seen in the current Energy Efficiency policy which provides subsidies up to €560 for oil and gas home heating boilers while there is no financial aid for a renewable alternative such as a heat pump[SEAI, 2011]. This example outlines a governmental institutional lock-in which encompasses vested interests from a wide range of actors such as; technology manufacturers, fossil fuel distributors, buyers, sellers, etc. The example given restricts an alternative technology, not allowing an even playing field in terms of opportunities to gain a stakehold in the market.

To counter the technological aspect of a TIC, Unruh suggests three policy approaches that would progressively disrupt technology-based issues of lock-in. The first is based on treating the end products of a process and not changing the process itself, known as 'end of pipe', e.g. carbon capture technology. The second is an approach that changes or modifies parts of the process but maintains the overall system structure, known as 'continuity', e.g. changing a gas turbine from operating on natural gas to a biogas, or synthetic natural gas. The last option is based on total change and replacement of the system structure; known as 'discontinuity', e.g. retro-fitting a power plant from coal-fired to gas-fired.

In the context of this report the second approach (continuity) is applicable - changing components or how a process is carried out, making the transition from past to present. Thomas Edison can be used as a perfect example of this approach. Edison understood that his vision of electric street lighting would clash with the locked-in illumination system of the time. To counter this Edison created links with the current method, his idea was to narrow the divide between technologies, allowing for a more fluid transition. Edison cleverly describing his new concept in gas terminology such as 'burners' and 'mains', then using existing gas infrastructure; pipelines, lampposts, etc., to physically transfer the electricity to its destination and sucessfully get his concept in place[Bright, 1950]. In doing this, Edison minimised the perceived technological change and successfully brought electricity to street lighting, changing illumination forever.

[1] Source:[Keynes, 1935]

In this report, continuity is a key factor in changing the oil-based paradigm evident in Ireland's heat sector. For example heat pumps could be an ideal solution to the RES-H issue because electricity and a heat sink is all that is necessary to operate. In terms of continuity, some types of heat pumps such as air sourced can be installed as a direct replacement for an oil boiler without any retrofitting being necessary[Deane et al., 2014]. Again this is a component change not the entire system, similar to the Edison example. However the real obstacle is the source of the lock-in, identifying and addressing each source within the heat sector is essential. This aspect will be discussed in the literature and analytical chapters of the report. In the case of heat pumps, development into wider niches may be necessary for confidence to grow in the technology in all sectors, for example; large scale/commercial sectors or district heating systems. As Unruh alludes to; *technological change can be more of an institutional issue than a technological issue due to their respected rate of evolution*[Unruh, 2002].

Hypotheses

To continue onwards from what has unfolded in the chapter thus far, two hypotheses have come to the fore. While keeping in mind the fundamental principle of the report to facilitate technological change in the heat sector, the following needs to be addressed in the remainder of the report.

- Public regulation measures and proposals must be critically analysed, showing the unbiased effects and results from a heat sector perspective. Emphasis must be put on the governmental institutional lock-in.
- In conjunction with the first hypothesis, is there change evident from the organisational actors of this study, and if so, is there evidence of active lowering of barriers.

The hypotheses can be seen as the defining factors to the theoretical framework used in this report. This report sets out to analyse, test and even develop the hypotheses into more suitable metamorphosis of the original. The following section outlines the theoretical approach to accompany this framework.

2.2 Theoretical Approach - Choice Awareness Theory

Techno-institutional complex outlines two fundamental areas of this report, first 'to identify technological and institutional barriers' and secondly 'to successfully implement change'. The theory behind choice awareness is inline with the framework laid out in this chapter. For this reason a brief introduction is given, followed by a diagram outlining the theory and each step in the process before relating choice awareness to the context of this report. The following statement from Lund's publication regarding choice awareness has a deep resemblance to the situation this report encounters[Lund, 2010]. The statement also reinforcing the decision to include the theory in this analysis –

"When society defines and seeks to implement objectives implying radical technological change, the influence and discourse of existing institutions will affect the implementation. Such impact will hinder the development of new solutions and eliminate certain alternatives and will seek to create a perception indicating that society has no choice but to implement technologies that will save and constitute existing positions." [Lund, 2009, p.28]

Consumer choice and awareness of alternatives is the key aspect that suffers in a situation where TIC or any type of lock-in is in effect. On a societal level, if the collective feels that no alternative to the current path dependency is available then the lock-in has achieved its goal of disrupting change. Choice awareness theory is based on the concept of unearthing alternatives that have previously gone unnoticed and give choice to the consumer. The theory is used when trying to implement a technological change which according to Muller et al., occurs when more than one of the fundamental constituents of technology has been altered; knowledge, product, organisation, and technique[Muller et al., 1984]. Choice awareness theory is based upon a four step strategy, see figure 2.1 for details. Steps 1-3 consist of designing concrete technical alternatives, carrying out feasibility studies based on institutional economics, and public regulation measures and proposals. These three steps are connected to the final step which is the promotion of a new-corporative democratic infrastructure.

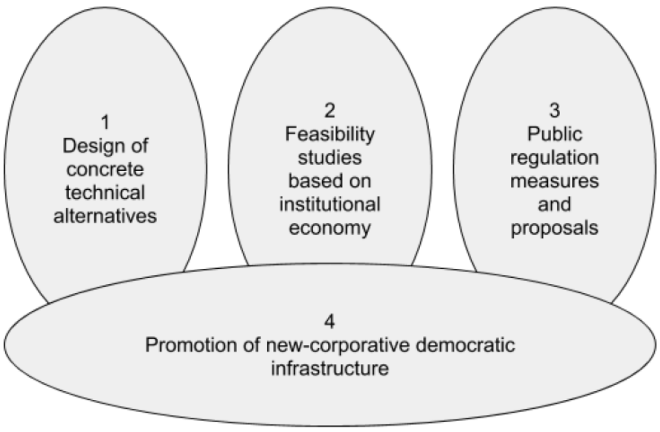

Figure 2.1: The choice awareness strategies[Lund, 2010]

In the context of Ireland's overall energy system, techno-institutional complex is evident. However this report only looks at a small segment of this system, and of the small segment it analyses the prospect of only one concrete technical alternative to solving or even easing the RES-H target issue; heat pumps. The design of concrete technical alternatives is limited to one for this report, also only one public regulation measure proposed shall be investigated showing the effects of each on both the heat and electricity sectors. No feasibility study will be carried out based on the institutional economy due to resource constraints. This report will show that incorporating the continuity policy approach along with choice awareness theory can break down some of the barriers to technological change.

2.3 Research Framework - Structure, Design, and Methodologies

This section concentrates on creating the research methodology to allow the study content to be analysed in conjunction with the theoretical approach outlined in the previous section so the research question, sub-questions and hypotheses can all be examined and answered. The first step is to outline the report structure which explains what each chapter entails and how they fit into the overall report. Each of the different research methodologies used during the analytical phase are discussed next, giving an insight into how each operate and what they achieve.

Report structure

Part 1: Introduction, research question and thesis perspective - Chapter 1 outlines the entire study content, setting the platform for the research question and sub-questions to be formulated, which along with the delimitations set the tone for the rest of the report. Chapter 2 introduces the thesis perspective, discussing both the theoretical and methodological approaches necessary to analyse the study content and to successfully arrive at an optimal solution or optimal solutions. Considerable depth in relation to the theoretical framework and theoretical approach is delineated in chapter 2 with techno-institutional complex and choice awareness theories outlined as being valid concepts to consider when analysing the study content. The second part of chapter 2 describes the research methodologies and research design used in the report.

Part 2: Literature review - Chapter 3 provides and insight into the study context using a literature review. The chapter gives a thorough background into Ireland's heat and electricity sectors, followed by a discussion on energy efficiency and heat pumps. When looking into the heat and electricity sectors the respective markets are deliberated, discussing the incentives available, current and future outlooks for each. Energy efficiency is discussed next, analysing its overall importance to all energy sectors in Ireland. The final section introduces heat pumps, starting with a short overview then reviewing the different types and finally discussing how both the heat and electricity sectors could be integrated using the technology alluded to in the chapter.

Part 3: Sector analysis - The analytical section of the report starts from chapter 4, looks into Ireland's heat sector and also includes chapter 5 which looks at the nation's electricity sector. Initially a consumer choice heat model is used to create scenarios based on heat pump uptake in the Irish heat sector. This information is then developed into hourly demand profiles for the entire year of 2020 using an excel model which incorporates various things such as weekday and holiday occupancy patterns and summer cut-off. A policy proposal is outlined in this chapter to encourage heat pump uptake. Once chapter 4 is complete, electricity demand profiles for each scenario are created and ready to be added to the overall electricity system demand. Chapter 5 concentrates the analysis on the All-island electricity system. Using the aforementioned extra demand, these are used with the expected system demand and simulated in PLEXOS to see if the system changes much to provide the extra electricity necessary. The effects of the extra demand are analysed thoroughly to identify any changes in operational strategy to provide the extra demand. Each of the two chapters finish with a section concluding their own findings.

Part 4: Conclusion - Chapter 6 reviews the entire report, bringing together the problem formulation, analysis and results to summarise the report and finalise the concluding remarks. This chapter revisits the research questions, hypotheses and other stand-out comments to review if the report actually found solutions or gave insights into any areas of concern in either the heat or electricity sectors.

Case study

A case study is the type of research design used in this report. It acts as a framework that provides boundaries that research methodologies analyses within. As an empirical investigation, it allows a theoretical situation be subject to a range of stimuli. This report is primarily based on analysing the effects of heat pumps on the electricity sector however for that to occur, certain stimuli derived from policy decisions/support for heat pumps will be simulated using two types of computational analytical tools. An advantage of using a case study is it allows theoretical hypotheses to be tested in a real-life scenario, such as the two outlined in the previous section. Some debate can be found questioning the validity of a case study in relation to the broader, more widespread use of the theory or hypothesis, such as publications from Andersen for example[Andersen, 2008]. However to balance the debate the quote below from [Flyvbjerg and Richardson, 2004] who are proponents of case studies and their validity is stated.

"One can often generalise on the basis of a single case, and the case study may be central to scientific development via generalisation as supplement or alternative to other methods. But formal generalisation is overvalued as a source of scientific development, whereas "the force of example" is underestimated" [Flyvbjerg, 2006, p.228]

Literature review

This report uses the literature review to gain an understanding of certain aspects which are essential for thorough analysis to be carried out. Insights into how Ireland's heat and electricity sectors operate is vital to ensure quality proposals are recommended for future development. Recalling the theoretical approach outlined in the previous section, Choice Awareness, the initial step; creating concrete technical alternatives, relies heavily on this research methodology.

The main uses of a literature review in this report is to gain a full and complete understanding for the markets; be knowledgeable about the support schemes and incentives available; recognise the technological and institutional lock-ins in operation in each sector, and to see how the theoretical approach outlined in chapter 2 can be implemented to achieve technological change. A literature review is generally known as being secondary data sourcing, in this report all data is referenced throughout and originates from credible sources such as the Department of Communications, Energy and Natural Resources, Sustainable Energy Authority of Ireland, and the Central Statistics Office of Ireland.

Thermal energy system modelling - consumer choice heat and excel models

To build the thermal energy supply scenarios necessary, a consumer choice heat model is used along with a simplistic excel model to create hourly load profiles. The consumer choice heat model was SEAI commissioned and created by Elementenergy[2]. The primary function of the heat model is to assess how technologies in the heat sector are affected by changes in policy, market conditions, and other external situations, giving an insight into different consumers and their response to change in Ireland's heat sector.

The heat model accounts for 35 different consumer types and various categories based on exogenously inputted data, covering everything from available support schemes, capital, operational and hidden costs, to published data from the Central Statistics Office (CSO). The ability to evaluate the outcome from different consumer viewpoints is rewarding to the overall result, as the defining factor that could alter the path dependency for a domestic consumer towards an industrial consumer varies greatly. For example; a domestic consumer could rate hot water requirements as a low concern and installation issues as a high concern; whereas an industrial consumer could view hot water heating requirements as a high concern, while retrofitting only a low concern. These 'concerns' are registered as consumer coefficients in the model. This level of knowledge regarding consumer choice is integral in correctly matching the technology to the consumer within the model. The next step the heat model takes is to calculate consumer choices for the period in question, developing a market share (uptake) for each technology type in the scenario. Details of all formulas and assumptions used in the consumer choice heat model can be seen in appendix 7.1.

Once the consumer choice model indicates the level of heat pump uptake for each scenario, this information is used in combination with an excel model to create hourly heat load profiles. The excel model uses recorded weather temperatures, heating degree days, and a concept from a UK National Grid report called Composite Weather Variable (CWV) to create an accurate profile[UK National Grid, 2007]. CWV is a methodology used to scale gas demand while incorporating human factors and climatic conditions into the calculation; including summer cut-off, holiday de-rating, effective temperature. A correlation is identified between gas usage and heat demand in the analysis. This will be explained in detail in the chapter. The model outputs an hourly heat load profile which is used as a base to be scaled to find the overall thermal and corresponding electrical demand for the period.

[2] Elementenergy is a strategic energy consultancy group[Elementenergy, 2014]

Electricity system modelling - PLEXOS

PLEXOS power market simulation software (hereafter: PLEXOS) is used to solve for both unit commitment and unit dispatch in this report. This was carried out by creating a dispatch model of the All-island electricity system. PLEXOS is a modelling tool designed for energy market analysis. It is especially effective in situations where user-defined requirements such as; capacity expansion planning, high levels of renewable energy integration or energy storage management need to be accommodated.

Glenn Drayton created the power system modelling software, and in turn founded Drayton Analytics (now called Energy Exemplar) in 1999. Energy Exemplar currently deliver PLEXOS as a power system modelling software for commercial use. Free trials to non-commercial users for a limited period of six months are also be provided. PLEXOS software has become a leading energy modelling tool used worldwide by utility companies, transmission system operators and energy regulatory bodies. The software has been used to model Ireland's electricity system in recent years by the Commission for Energy Regulation. With its reputation for unprecedented accuracy and robustness, Ireland's SEM adopted PLEXOS as the standard simulator.[Energy Exemplar, 2013]

PLEXOS modelling entrusts the co-optimisation of all system and market aspects to the implementation of the embedded solver algorithms. Using mixed integer programming (integer optimisation) all manner of generation, constraint, and reserve requirements are taken into account to calculate the best solution for the given task. Multiple levels of detail are utilised when the solver is optimising unit dispatch, from ramp rates on generators to ensuring the sustainable operation of hydro plants. In a similar way, all relevant system constraints and ancillary services requirements are adhered to while the model solves in each interval; matching system generation to system demand. This modelling software avoids issues of un-economical unit dispatch by incorporating two features into its software; perfect foresight, and look-ahead. The former is utilised when non-deterministic or stochastic elements are present in the model, such as unfixed wind generation or system demand. The look-ahead feature is an additional foresight to perfect foresight which allows an insight into the following day. Both features allow for anticipatory action to be taken if necessary, allowing for more accurate decisions on unit dispatch. The length of each foresight feature is user defined.

Others features of PLEXOS include the ability to create maintenance schedules, demand profiles, generation profiles, and a range of other types of profiles. For example if no maintenance schedule exists for a generator one can be created based on the Monte Carlo simulation algorithm. This creates a schedule using the forced outage rates and maintenance rates inputted to the model for the generation plant. In a similar way system demands and various other types of profiles can be created using either endogenous or exogenous stochastic sampling. Using a base profile with inputs such as; error standard deviation, auto correlation, min/max value, and mean reversion, a new profile can be developed for a particular situation.[Energy Exemplar, 2013]

Study Context 3

This chapter looks at the study context of this case study. The chapter describes each element by concentrating on the current situations and the expected future development up to 2020. Firstly the heat and electricity sectors are examined allowing an insight into the various aspects of each sector, followed by a section concentrating on energy efficiency and its importance to the entire concept of reaching renewable targets is discussed. Finally an overview of heat pumps is included, explaining their operation, benefits, drawbacks, and different types of the technology.

3.1 Ireland's Heat Sector

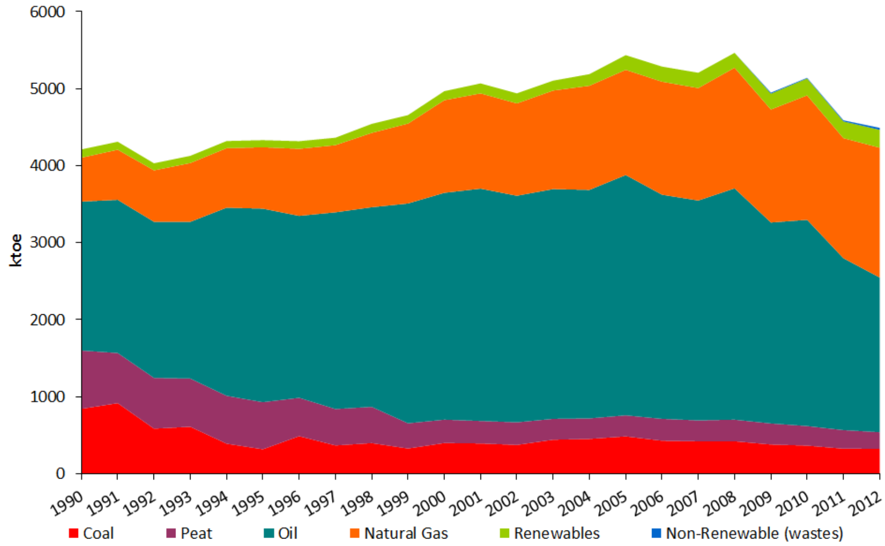

Figure 3.1: Total final consumption of heat by fuel, 2012

Of Ireland's total primary energy requirement (TPER) in 2012, thermal energy demand accounted for 33%. The fuels contributing to the heat demand in Ireland since 1990 are shown in figure 3.1. In 2012 the two largest fuel shares were oil (45%) and natural gas (38%). Compared to 2011, the oil share decreased by 4% while the natural gas increased by the same amount[SEAI, 2013b]. It may be worth noting that in a number of energy-related graphs in the Irish context, the overall demand from 2008 onward is in decline. This phenomenon can be attributed to the economic downturn in Ireland.

Heat market penetration in Ireland's residential sector

Oil-fired central heating in the residential sector accounts for over 700,000 households, while gas-fired central heating is used in approximately 550,000 households according to the 2011 CSO census, see table 3.1 for details[CSO, 2012]. This pattern is in contrast to many other European countries where gas usage in the EU-27 residential sector is 2.7 times higher than oil. Similarly in the industrial and commercial sectors, Ireland's oil usage is much higher than the EU average. Of the households with oil-fired central heating in the residential sector, 300,000 are in urban areas and one third of those are within 20 metres of the nearest gas supply. This trend of high level oil usage is unusual considering the benefits of natural gas, such as high combustion efficiencies, low cost, less CO_2 emissions and reducing Ireland's fuel import dependency. In fact gas prices are predicted in the IEA World Energy Outlook 2012 to be less than half the price paid for oil in future scenarios. [Irish Academy of Engineers, 2013] Table 3.1 outlines the range of heating systems by dwelling type in the residential sector.

	Detached	Semi-detached	Terraced	Flat/Apartment	Bed-sit	Not Stated
No Central Heating	11,268	4,287	6,843	3,790	439	325
Oil	460,525	171,555	64,549	9,536	842	4,325
Natural Gas	81,715	226,249	161,453	74,426	1,324	5,048
Electricity	16,801	15,022	19,922	83,728	2,758	2,188
Coal (incl. Anthracite)	34,388	22,383	19.672	1,507	60	1,135
Peat (incl. turf)	62,413	9,782	5,083	505	37	818
Liquid Petroleum Gas	6,480	2,163	1,040	685	34	50
Wood (incl. wood pellets)	17,399	2,248	1,164	429	14	141
Other Fuels	5,775	925	579	1,124	47	74
Not Stated	3,105	2,037	1,520	1,857	140	13,679
Sub-total	699,869	456,651	281,825	177,587	5,695	27,783
Percent Share (%)	42	28	17	11	0	2

Table 3.1: Breakdown of the heating systems by dwelling type in the residential sector[CSO, 2012]

Renewable heat

In 2012, RES-H represented a 5.2% share in thermal energy consumption. This share needs to rise to 12% by 2020 to comply with the Directive targets. The RES-H breakdown into each generation type is shown in figure 3.2. Biomass contributed 4.4% to the overall value with geothermal, biogas and solar making up the remainder.[SEAI, 2014] From figure 3.2 it can be seen that biomass has been the main source of renewable heat for many years and still proceeds to grow year on year. Geothermal and solar also show signs of growth in more recent years. The introduction of incentive schemes such as REFIT 3, Greener Homes and the Renewable Energy Heat Deployment (ReHeat) programmes helped to boost the levels of renewable heating in both the residential and services sectors. Renewable energy contributed from heat pumps is included in this graph. The different types are grouped together under the geothermal label.

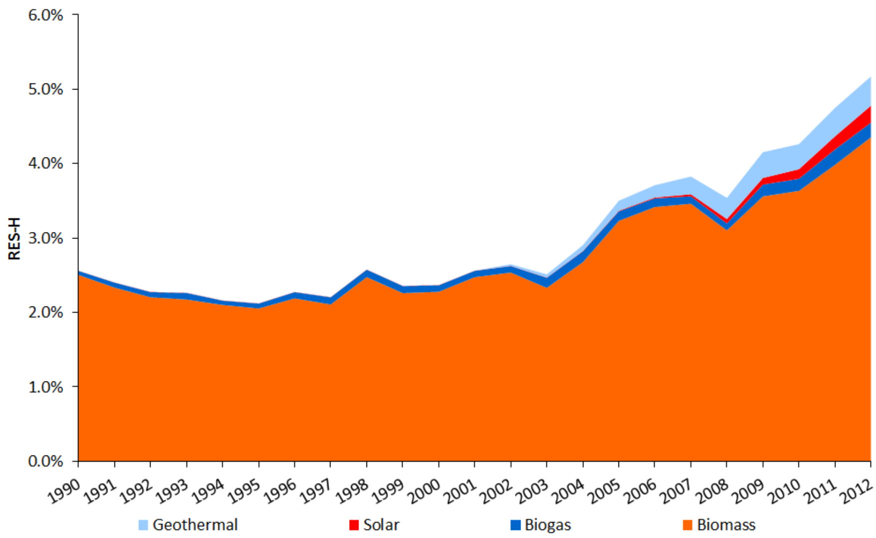

Figure 3.2: Renewable energy contribution to thermal energy (RES-H)

Past and present renewable heat incentives and policy support

The previously mentioned schemes, the Greener Homes scheme and ReHeat programme were support mechanisms provided by Ireland's energy agency. The Greener Homes scheme provided grants for home owners to purchase home heating systems that use renewable energy, while ReHeat provided financial support for heating systems in non-residential buildings. Both schemes were responsible for the large increase in renewable heating, however both have since closed. The follow-on scheme know as Better Energy Homes scheme started in 2011 and concentrates on different areas of society. This scheme is discussed further in the Energy Efficiency section 3.3. Another policy decision that encouraged the uptake of renewables is outlined in 'Part L of the Building Regulation of Ireland'. The regulation requires that all new residential buildings to install a renewable energy source. This regulation made a large difference in the RES-H sector and is expected to continue doing so[DECLG, 2011]

In February 2012, the REFIT 3 scheme was launched which allocates a fixed 15 year feed-in-tariff for biomass technologies. The tariff is open for applications until 31/12/2015. Other support mechanisms are also in effect in Ireland such as investment grants for solar thermal technology and tax reliefs for other renewable technology types. As pointed out in chapter 1, analysis alluded to by SEAI find that even in the most optimistic scenario, Ireland's RES-H targets will not be met unless there are changes to current renewable heat policy. Promoting renewable technologies such as heat pumps would be one way of reaching the RES-H targets, another is to target a reduction in energy demand, and in effect lower the overall target.

A report carried out by SEAI for the Department of Communication, Energy and Natural Resources (DCENR) analysed the expected level of renewable heating in Ireland by 2020 if existing policies are upheld[Clancy, 2014]. The suggested effects from modelling five policy alternatives are shown in figure 3.3. The 'No policy' option is simply business-as-usual, letting the market decide which type of technology is best for the consumer. The analysis was based upon the World Energy Outlook 2012 fuel prices for the years up to 2020 which includes the expected rise in fossil fuels costs. Rising fuel prices could slowly result in more consumers switching to renewable technologies when replacing or installing a new heating system. Figure 3.3 illustrates this slow change with a slow increase in RES-H in the 'No policy' option. Part L Regulation shows a steadily increasing effect, helping to meet the targets. 'Solar Thermal Grant' and 'CHP REFIT' (REFIT 3) show little or no benefit to the RES-H targets as there is only a slight uptake of either support schemes. Of the four policy changes shown in the figure, 'Energy Efficiency' is shown to have a large effect on the targets. This is possible by reducing the overall targets through a more energy efficient energy sector. The most noteworthy thing to take from the figure is that even with all the policy options availed of, the levels of RES-H still fall short of the 12% share.

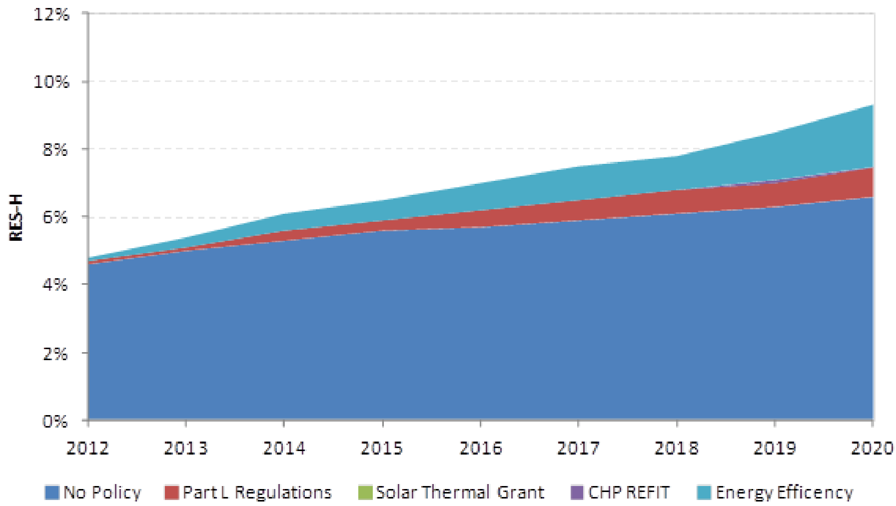

Figure 3.3: Effects of existing policy towards the RES-H target[Clancy, 2014]

Future incentives and support mechanisms to increase Ireland's RES-H

> "... *currently only one third of EU member states have concrete plans for implementing renewable energy heating obligations in line with the RES Directive.*" [RE-Shape, 2012, p.1]

Support policies for RES-H across the EU are generally not as well developed as with the RES-T and RES-E policies[IEA, 2012],[Connor et al., 2013]. Incentivised support for RES-T and RES-E in the form of biofuel obligations and feed-in-tariffs aided their respective causes. For the heat sector, disjointed support schemes come and go, making their impacts in the short term but not committing for the long tenure. This is one of the first barriers to address in proposing policy changes in the heat sector[Ragwitz et al., 2012]. As of May 2014, Ireland's government published a green paper on Energy Policy. The paper itself is non-committal and without targets at this stage, yet it seems to be a step in the right direction for Ireland. The green paper asks questions in relevant areas of Irish energy policy that are currently under debate in many quarters, for instance: electricity trading with the United Kingdom, upgrading transmission lines, renewable energy progress and targets, and nuclear energy. The publication also mentions that a 'Bioenergy Strategy' is to be published in the near future. The content of which is unknown but has the potential to make significant change in the heat sector[DCENR, 2014].

From a supranational context, across the EU there are many policy types used to encourage renewable heat policy. Renewable energy support schemes can be broadly divided into three categories; Regulation, Incentives, Soft Measures. The regulation category covers aspects such as building regulation and carbon taxes. Incentives cover tax exemptions, feed-in-tariffs, feed-in-premiums, bonus payments, quotas etc. The soft measures category entails education, awareness and up-skilling personnel through training. Figure 3.4 shows a summary of the preferred type of RES-H support mechanisms availed of in the EU[European Union, 2014]. From the figure it can be seen that the majority of the EU-27 use investment grants to support RES-H technologies. Building regulations and obligations, and tax exemptions are used in 13 and 11 countries respectively. The final category bonus/tariffs for RES-H are only used in 5 countries. This category is widely used in RES-E support schemes however in the RES-H sector there is little uptake of this type due to differences between the two sectors.

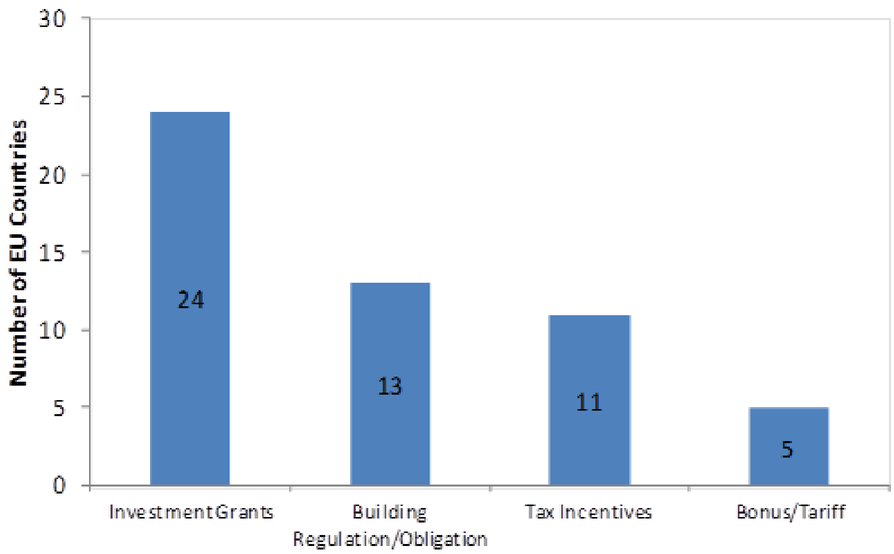

Figure 3.4: Summary of European support schemes for RES-H as of mid-2012

The four categories have different pros and cons which will be mentioned to in this paragraph. Investment grants rely heavily on governmental backing which is a large cost for the exchequer, but gives a positive perception to the public on their willingness to initiate change. Building regulations/obligations can have a side-effect of increasing public awareness to issues of energy efficiency for example, and also help premature technologies to increase uptake, gaining confidence in the market. However they can also leave the 'funding' organisation or exchequer open to criticism if the uptake falls short of targets. As with the previous option, tax incentives aid the uptake of new technologies, but they can also create a false market share which can collapse if the incentive is reduced or withdrawn altogether. Bonus/tariff schemes cover a wide range of possibilities, but in general they are adjustable in line with technology cost to make the option more feasible in one way or another. The cost of such a scheme can spiral very quickly unless some expenditure limits are stipulated in the infancy stages of the scheme.[Elementenergy, 2012b]

Barriers to technological change in the heat sector

This section outlines some of the main barriers that constrain the uptake of renewables within the heat sector in Ireland. Issues in relation to performance and cost, regulation and institutional factors, and long term support beyond 2020 are amongst the barriers discussed below. Some barriers are described as 'hard barriers', meaning they cannot be negated with additional capital expenditure (CAPEX) for example; lack of space. Whereas other barriers are seen as 'soft barriers' meaning they can be overcome with added CAPEX, for example; 'hassle barriers'. Hassle barriers can be described as costs representing the associated disruption of retrofitting a dwelling with new, more suitable radiators to the specific technology for example.

Issues with performance and costs of heat pumps are generally important points in any debate over heat pumps. As [Elementenergy, 2012b] outlines, the issue with heat pumps is that dramatic improvements are necessary for the technology to play a leading role in the heat sector. Case studies from Sweden suggest that improved COP is possible especially when installed in conjunction with low temperature heating systems. Consideration is also necessary when deciding on which the type or even if a heat pump can fulfil the consumer's requirements, for example; investigate whether a heat pump can deliver the necessary hot water temperature for consumer needs. This topic leads to the issue of technical suitability, and whether enough floor space is available for the heat pump or if there are negative environmental impacts from noise emanating from the heat pump. Many different aspects need to be looked into before investment should be made.

As of May 2014, Ireland has no capital investment support scheme to avail of when purchasing a heat pump. Subsidies or tax exemption in this area would reduce the gap that consumers are willing to pay for a renewable heating system. This leads to the barrier of comparable time discounting with conventional heating systems based on CAPEX and operating expense (OPEX). Consumers want short payback periods so the technology pays for itself in the shortest possible time and OPEX is the sole cost from thereafter. Evidence from a UK Energy Savings Trust heat pump study shows that a ground source heat pump is not competitive with either a gas or oil boiler (although it is more competitive than a biomass boiler)[Energy Savings Trust, 2013].

A relevant institutional barrier to this report can be best described using a landlord-versus-tenant situation. If incentives were in place for investment in a renewable heating system, who should pay and who benefits more from a renewable heating system? landlord or tenant? Typically the landlord would be expected to front the CAPEX, whereas the tenant reaps the rewards by lower heating costs. Unless the landlord can somehow recoup the capital expense through higher rent it does not make economic sense to invest. This type of institutional barrier can be seen in a number of areas where CAPEX and OPEX are separated in an organisational structure.

A subsidy or tax exemption on the capital investment may be enough for the consumer, but for suppliers on the other hand, long term policy decisions beyond 2020 are essential for their investment into the market[Ragwitz et al., 2012]. If the investment by suppliers into supply chains is made, then the seed is sown and the renewable technology market in Ireland could be bolstered. To help this transition from conventional heating systems to renewable alternatives, technology trials could prove a worthwhile experiment as the Energy Trust UK Heat Pumps trials have shown - making consumers aware of an alternative choice in heating systems[Energy Savings Trust, 2013]. This step would be seen as a major part of the continuity approach mentioned in the theoretical framework laid out in section 2.1.

Awareness is a very interesting concept with respect to technological change, an issue which is embedded into this entire report. In addition to awareness, timing and sequence are another two fundamental elements that can assist technological change. Diffusion theory suggests that the 'S-Curve' of technological adoption is based on early adopters, followed by a time of quick uptake, and then a dwindling period as the last adopters invest in the concept[Karakaya et al., 2014]. But what starts the second stage of fast growth? Could be it a policy decision, tax exemption, combination of timing and sequence, or a combination of many different aspects connected to the market.

3.2 Ireland's Electricity Sector

On 1st November 2007, the Single Electricity Market (SEM) came online as a platform to trade electricity from both the Republic of Ireland and Northern Ireland electricity systems as one, also known as the All-island electricity system. This platform created a mandatory electricity pool market for all electricity trade. As the All-island electricity system is a combination of two jurisdictions it contains two transmission system operators (TSO); SONI and EirGrid. These system operators are mandated to operate the All-island electricity system, ensuring a secure and stable electricity service is available. While taking into account all system constraints and reserve requirements the operators dispatch generators based on the guidelines outlined for the operation of the SEM.

For generators in the SEM, all plants over 10 MW are required to feed the electricity produced into the electricity pool. Suppliers purchase electricity from this pool and distribute the electricity through the electrical infrastructure around the system[CER, 2013]. To feed into the pool, generators bid for the sale of their electricity to the market, these bids are based on their short-run marginal cost (SRMC) and ranked from low to high creating a merit order. This ensures generators with the lowest SRMC are dispatch first, leading to more expensive bids until the demand has been fulfilled in that particular half hour. The price that all generators receive is set by the last generator to be dispatched in that particular 30 minutes period and is known as the system marginal price (SMP).

Alternatively it is possible for generators to receive payments for other services provided. In the SEM there are only two alternatives; capacity payments or dispatch balancing costs (DBC). Capacity payments are made to generators whom ensure that generation capacity is available if necessary for up-regulating or down-regulating depending on the requirement of the system. DBC is a payment which is similar to capacity payment as it exists to retain a stable and secure electricity system. DBC's accrue when the TSO is required to deviate from the merit order for the sake of system security.

Incentives and policy support

The Public Service Obligation (PSO) is a levy on electricity consumers to fund government policies in the electricity generation sector. Initially the PSO was established to subsidise peat-fired electricity generation plants for security of supply reasons[1]. Later it supported some gas CCGT and CHP to ensure adequate system security, along with schemes to incentivise the uptake of renewable energy technologies that reduce CO_2 emissions. As of 2012, Peat accounted for 29% of the PSO, fossil fuel security of supply contracts 30% and renewable electricity 41% [CER, 2012b].

Ireland's three peat-fired generation stations do not need to bid into the merit order for dispatch. These plants run in a must-run status when available. The system operator will restrict their dispatch only to abide by the dispatch rules[SEM Committee Decision Paper, 2011] or for system security reasons. In the case of renewable energy technologies such as wind, they have zero fuel cost and tend to be dispatched in the market when the wind generated electricity is available due to the low SRMC. However if a renewable generator is in the Alternative Energy Requirement (AER) scheme and the SMP is not high enough to cover its long term cost, the PSO provides a top up to ensure the economically feasible operation of the generator. If on the other hand, the SMP is higher than necessary for the long term cost of the renewable generators to be covered, then the wind farm will pay back the additional market revenue into the PSO, this type of incentive is referred to as a Feed-in-Premium. Renewable generators in the REFIT scheme (from September 2007 onwards) receive no additional revenue to cover long term cost, instead a fixed payment is received for each unit of electricity produced over a fixed period of 15 years.[DCENR, 1998] The market price reduction due to these generators has tended to cover the cost of the PSO funding.[O'Mahoney and Denny, 2011], [SEAI and EirGrid, 2012]

Electricity generation in Ireland

Figure 3.5 illustrates the type of generation Ireland has utilised for electricity generation since 1990 to 2012. In 2012 the gross final electricity profile consisted of 49% gas, 20% coal, 19.6% (normalised) renewable energy and 9% peat, the overall profile has changed quite an amount in recent years. The decline in oil increases in gas and renewables being the most striking aspects from the figure. The reason for these trends could be due to one of many factors; the

[1] This subsidy for peat fueled stations is not expected to be renewed after they expire (2015 for Edenderry and 2019 for West Offaly and Lough Ree) according to the green paper on Energy policy[DCENR, 2014]

increase in oil price; the need for more large flexible generation plant to maintain system stability (e.g. CCGT); the EU's influence in promoting renewable energy uptake, etc.

To follow on from a point alluded to in the previous paragraph in relation to large scale flexible generation capacity, the All-island electricity system experiences high levels of variation which can spur from a few select sources. Figure 3.6 exemplifies one source of these variations when it shows the weekly average system demand for the 2012 All-island electricity system from both the summer and winter perspective. The difference between the average weekday peak demand and weekend valley is in excess of 3GW. This presents a substantial variability in the 2012 system demand. The current generation portfolio in place maintains the grid requirements and manages with this large system demand variability[2].

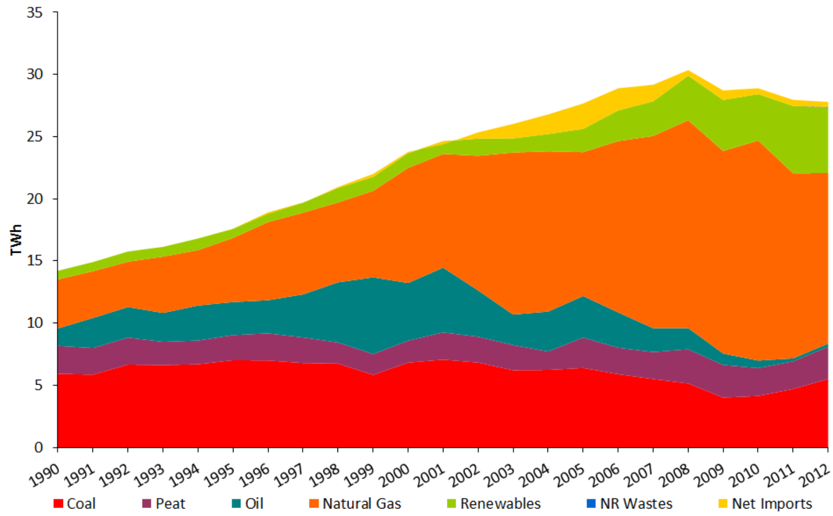

Figure 3.5: Gross final electricity by generation type, 2012[SEAI, 2013b]

All-island system variability and uncertainty

Variation and uncertainty can arise from a number of sources such as; stochastic renewable generation output (i.e. wind and solar), forced outages, and system demand as seen in figure 3.6. Additional variability in the system has the effect of increased *ramping* and *cycling* of thermal plant generators. Ramping occurs when generators are required to ramp up and down electricity production, generally this happens when there is variability in the system or forecasting is not accurate which requires change in electricity production to preserve the system stability. Cycling occurs when generators are required to start-up or shut down for system stability. In relation to any thermal combustion process, running at a constant optimal output is the preferred operational condition - ramping and cycling increase fuel use which lowers efficiency of the process, and increases variable operation and maintenance costs (VO&M) as a result of additional thermal stresses induced by a non-optimal operating pattern.

[2]For further details see: [CER, 2013]

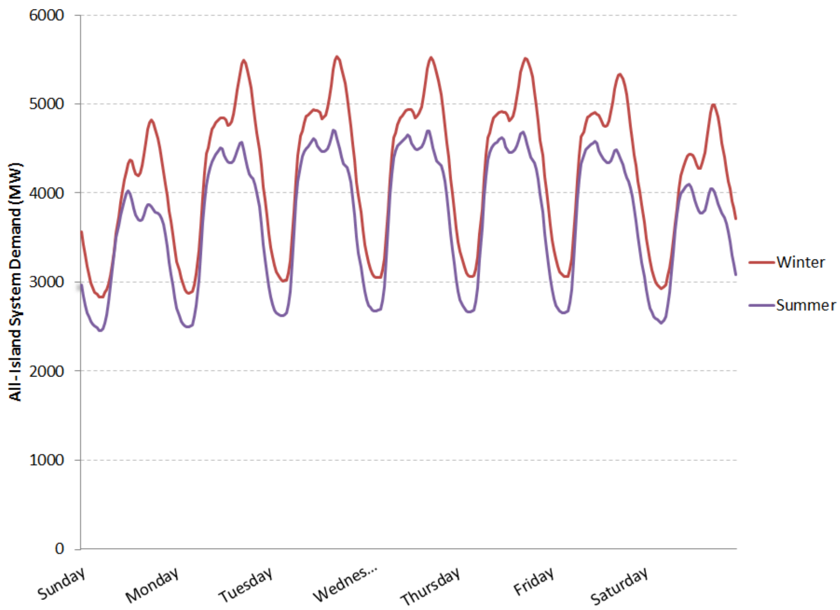

Figure 3.6: Weekly average system demand for the All-island electricity system in 2012

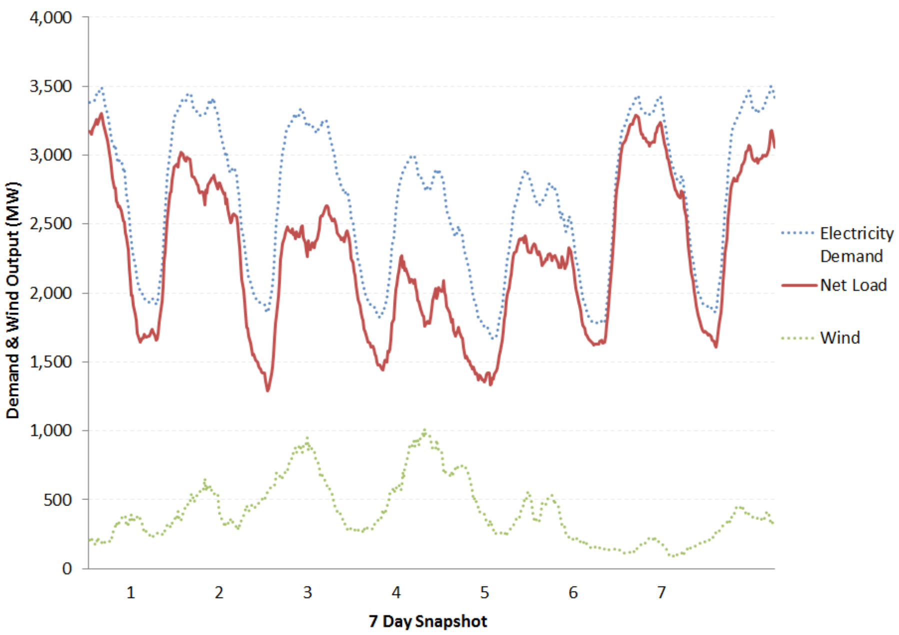

Figure 3.7: Profile of wind output, system demand and net load

As figure 3.6 points out, the profile and magnitude of the average daily demand variation is quite extreme. Variation has a tendency to decrease as time resolution increases. For example when analysing 2012 load data for the All-island system at a 15 minute resolution the average load change was 40 MW, when analysed at a 12 hours resolution the average load change was 872 MW, equivalent to over 4 times the largest plant in the All-island system[Holttinen, 2005],[Clancy and Gaffney, 2014]. Similarly variations in wind power reduce as time increases. Hydro power is another generation type that has a variable response however this is due to an external factor; weather patterns or more specifically rainfall. This would be regarded as a seasonal variation rather than daily or hourly. While variations due to renewables and demand are comparable and seem similar from the outset, it is important to consider the collective effect of these variations. Evidence suggests that electricity demand and wind output do not correlate strongly[DCENR, 1999]. Figure 3.7 illustrates that the variation in 2012 from wind power has an almost equal chance of offsetting demand variability as add to the overall variability. The figure shows this by combining the effects of wind output and system demand to illustrate the 'net load'. The net load is the demand left to meet after wind power is subtracted.

The ability to predict demand and generation while maintaining system stability and security is a function of the system operators. Based on the most accurate forecasts that the system operators can avail of, they decide based on the merit order as previously mentioned, which generators are dispatched in a certain hour of the day. Many variables also come into play at this unit commitment and dispatch stage because various types of generators have unique requirements for the most efficient operation. This procedure is dependent on the accuracy of forecasting, however in the case of over or under estimating electricity generation there are other features of the system included to maintain system integrity, i.e. reserves.

System reserve and flexibility

The All-island electricity system contains four reserve classes; primary, secondary and tertiaries 1 and 2. Primary reserve is required to cover between 5-15 seconds after an unexpected event occurs, then secondary takes over from primary to sustain electricity production, maintaining a stable frequency between 15-90 seconds[Eirgrid, 2013b]. These first two reserve classes are provided by synchronous plants and pumped hydro storage that are online and ready to provide electricity instantaneously if necessary. Tertiary reserves are replacement reserves and generally provided by offline generators. Tertiary 1 is required to be online within 90 seconds, while tertiary 2 is within 20 minutes and obliged to last 4 hours[Ela et al., 2011].

System flexibility is an essential part of providing a secure and stable system. Yasuda et al., outlines that as a relatively isolated island system, the issue with system flexibility in Ireland is not a new or entirely wind-orientated concern[Yasuda et al., 2012]. As a result the All-island system has been developed to handle large short term changes in demand or generation output through a flexible generation portfolio[IEA Task 25, 2012]. Yasuda et al., identifies factors that influence power system flexibility which has the effect of accommodating variable renewable electricity generation. Interconnection, pumped storage hydro and conventional hydro capacity along with combined cycle gas turbine (CCGT) capacity are outlined as the main sources of flexibility in the All-Island system. Interconnection, hydro and pumped storage capacities provide flexibility without prompting cycling or ramping emissions which is in contrast to CCGTs and open cycle gas turbines (OCGT).

The All-Island grid study carried out by the system operator was a technical study which delivered a basis for the current expansion of RES-E capacity towards 40% of gross demand in 2020[Eirgrid, 2008]. EirGrid analysed the operational and grid requirements of high RES electricity systems, from which the system operator decided it best practice to rollout the Grid 25 transmission grid upgrade plan and the DS3 programme[Eirgrid, 2010a]. Both of these actions aim to improve system flexibility and security while minimising network constraints to capitalise on benefits from RES into the future.

Renewable targets and the future of electricity generation

To achieve the 40% RES-E target the current renewable energy penetration will need to increase by over 100%. To estimate the percentage decrease that will occur in the other fuel types would be folly, however it could be surmised that high carbon-emitting fuels such as coal and peat would take a large cut in their share hold due to emission reduction targets also outlined in the above EU Directive. Another indication of the generation type which will be reduced is outlined in Eirgrid's 'Generation Capacity Statement 2013-2022' [Eirgrid, 2013a] where it is revealed that the system operator 'assumes some older generators will shut towards the latter end of the 10 year period'. This statement along with another from the green paper on Energy Policy which mentions that peat-fired plants will not get an extension to their PSO support once their current support expires could be understood to say that even though peat generation capacity will be present in 2020, it may not be utilised. The exception is Edenderry which is expected to be operating at 30% biomass in 2020.

In 2012, Ireland's electricity generation efficiency (the ratio of primary energy consumption to gross final electricity consumption) was 45%[SEAI, 2013b], which matched the EU average to within one percentage[Eurostat, 2014]. In a 2020 scenario with a higher percentage of renewable generation in the system, this conversion rate is expected to increase as no losses are accounted for between input and output of renewable generation such as wind or solar.

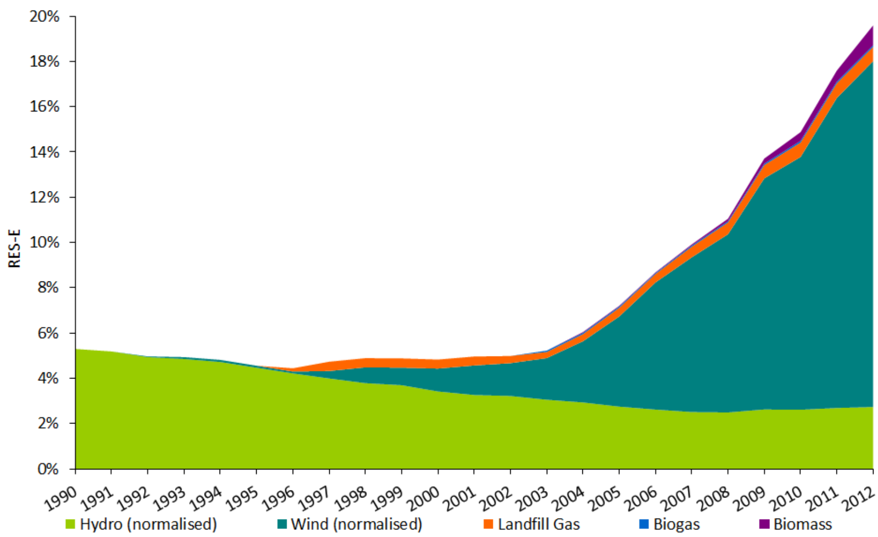

Figure 3.8: Renewable energy contribution to electricity consumption (RES-E) [SEAI, 2013b]

Figure 3.8 highlights the levels of RES-E in Ireland's electricity system since 1990. The most interesting aspect of figure 3.8 is the exponential rise of wind generation since the 1996 to current levels. Hydro had no increased generation capacity over the range of this graph and continues to annually generate approximately 750GWh. As the figure is illustrated in percentage rather than generation output, hydro represents a lower percentage of the total RES-E in more recent years because system demand increased. To reach the 40% RES-E target, the RES-E is expected to be generated from wind (31%), biomass (7%) and hydro (2%). For this to materialise a growth rate of 7.2% per annum is required.[SEAI, 2013a]

3.3 Energy Efficiency

'Energy Efficiency is internationally recognised as the most cost-effective means of reducing our dependence on fossil fuels and abating Green House Gas emissions.' [[DCENR, 2010a]]

The role of energy efficiency in the RES targets cannot be understated - lowering energy use, also means lowering renewable targets as they are a percentage of the total. From a European viewpoint, directives such as the EU Energy Services Directive (ESD) and Energy Performance of Buildings Directive (EPBD) have helped to bring the concept of energy efficiency to the forefront of many member state agendas. In 2007 the Irish government issued a white paper called 'Delivering a Sustainable Energy Future for Ireland'. This set an energy efficiency target of a 20% improvement across the whole economy by 2020 through the National Energy Efficiency Action Plan (NEEAP). In addition the energy efficiency target on the public sector was set at an ambitious 33% improvement[3]. The white paper seeks to reach this target by placing sustainability as the core of all Government's policies on environmental and energy issues hereafter. As a result of NEEAP, programmes such as the Greener Homes and ReHeat schemes, followed by the Better Energy Homes scheme were launched to ensure national targets are met[SEAI, 2011].

Past, present, and future energy efficiency support

The Better Energy Homes scheme subsidies; home insulation, heating system controls, building energy rating, solar heating, and replacement of old boilers with high-efficiency boilers - all actions that contribute in some way to the RES-H targets by either lowering thermal energy demand or increasing renewable heating. Since its launch in 2011, the Better Energy Homes scheme has spent €278 million helping over 258,000 dwellings to upgrade the energy efficiency of their homes. Recently with a further investment of €57 million by government the scheme will continue to upgrade the housing stock of Ireland, lowering the carbon footprint well into 2014. Energy efficiency measures outlined in NEEAP if fully implemented in the residential, public and services sectors could reduce demand substantially between now (2014) and 2020. The increased standard of the housing stock will significantly aid both the RES-E and RES-H targets, while also lower Ireland's non-ETS emissions.

[3] Both targets are compared to the average energy use over the period 2001 - 2005[DCENR, 2010a]

3.4 Heat Pumps

Heat pumps are recognised as a renewable energy source in EU Directive 2009/28/EC, and as a result can provide an effective and efficient means for Ireland to meet their 2020 renewable heating targets while also helping the nation's non-ETS target.

A heat pump is a device used to transfer thermal energy from a cold reservoir to a hot reservoir using an electrical input to create the energy transfer between the two reservoirs. The process that occurs is the same as a refrigerator - the only difference is whether the area is to be heated or cooled, as a refrigerator expels heat from the hot reservoir, a heat pump emits heat into the hot reservoir or heating space. In some cases heat pumps can be used as a direct replacement for an existing oil or gas boiler, but heat pumps offer the added advantage of facilitating hot water requirements.[Hewitt, 2012]

The main advantage of a heat pump lies in the cost of the thermal energy produced from the device. Based on the input energy sources for which there is two; cold reservoir and electricity, only the electricity used is an expense. Heat pumps can produce at the very least double the thermal energy output towards electrical energy used, this means the cost of a kWh output is half the cost of the kWh input. The performance of a heat pump is measured as the Coefficient of Performance (COP) - the formula for which can be seen below. In the formula Q_h stands for heat output and while W_{in} is the electrical input. Understanding the difference between efficiency and COP is important; efficiency is the ratio of energy output/energy input; COP is energy output/work input. COP does not include all energy inputs just electrical input, energy input from the cold reservoir is not account for. Otherwise a COP result over one would contradict the Law of Conservation of Energy which states - *'Energy cannot be created or destroyed only transformed from one form to another'*

$$COP = Q_h / W_{in} \quad (1)$$

One caveat of the EU Directive 2009/28/EC in relation to heat pumps is that the 'Seasonal Performance Factor' (SPF) is required to be above 2.52[4]. The SPF is the average COP of the heat pump over the entire heating season. This caveat is stipulated to account for inefficiencies in electricity generation. Depending on how efficiently electricity is generated, either using the EU-28 average from Eurostat or if available the particular member states efficiency, this SPF value can change.

Types of heat pump technology

In general heat pumps are categorised using their heat source, i.e. air, water and ground source heat pumps. All types operate using the same basic principle, using electricity to draw thermal energy out of a low temperature heat source, pass through a thermodynamic cycle which raises the temperature of the working fluid emitting heat energy into a heating space.

[4]Calculated using the methodology outlined in Annex VII of the Directive. This will be revisited in chapter 5

Ground source heat pumps (GSHP) use geothermal heat as the heat source. One of the advantages of this type is the constant temperature of the heat source which enhances the overall COP of the process. Air source heat pumps (ASHP) use the atmosphere as a source of heat. Unfortunately the air source type can experience large variation depending on the weather conditions. The COP can suffer further as extra electricity may be necessary to defrost the heat exchanger during cold conditions. Air source heat pumps are often chosen over the other types as they need the least amount of retro-fitting to install and can often be a simple replacement for existing heating systems.[Ochsner, 2008]

An aspect that could make heat pumps more attractive is the benefit of added intelligence into the technology. From a user point of view, taking control of the on/off feature is generally the standard operational strategy used by the mass volume of heating system owners. In recent times zoning has become more frequent, with bedrooms and living areas zoned differently to direct more spatial heating to the living areas at certain times of the day. This intelligence has expanded to remote device operated territory, using the internet via a smart phone or laptop, the heating system can be fully controlled from a remote location. These features are available in different types of heating systems however in the case of heat pumps the advantage is their ability to 'modulate' or ramp down their electricity usage. In times when the heat demand is low the heat pump will also lower while still maintaining the required temperatures. This leads to more efficient operation of the device and can also lead to other smart grid concepts. For instance all new Daikin heat pumps are produced 'smart grid ready'[Daikin, 2014], a feature best described using the German energy system.

In the German energy system, demand side management is becoming popular as a means for reducing energy related peaking. Companies (referred to as aggregators) can pool together a number of heat pump owners with whom a lower that average electricity rate is agreed, in exchange the aggregators have control over the heat pump usage in peak times[Biegel et al., 2013]. This means if necessary these heat pumps can be ramped down or turned off completely during these peak usage periods. This feature is another advantage of the technology which can be availed of when the market adjusts and develops the necessary infrastructure in terms of regulation and policy support in Ireland.

Integrating heat pumps into Ireland's heat sector

The future role of heat pumps in the Irish heat sector is yet to be fully utilised. A recent report by [Connolly and Mathiesen, 2014] analysed the potential for Ireland to achieve a 100% renewable system. The report included heat pumps along with many other technologies to reach the 100% target and it concluded that based on economic and technical analysis the concept is possible. This report only seeks to analyse a fraction of that carried out by [Connolly and Mathiesen, 2014] however the fact it was found feasible is a good indication for the proposal to integrate the heat and electricity sectors in this report.

For Ireland it would be advantageous to increase uptake of heat pumps as they are regarded as a renewable energy source in the Directive – meaning the output from the heat pumps would help to meet the 2020 RES-H targets. This concept of electrifying the heat sector using heat pumps would also displace non-ETS fuel use by using electricity to create heat, helping to meet the targeted 20% reduction in non-ETS emissions. Utilising this technology would have benefits for a wide range of the heat sector consumers because as already pointed out; heat pumps only need electricity and a source for the cold reservoir to operate. Once an electricity supply is present, a heating system can also be installed, increasing consumer choice when researching the best option for their heating system. Viewing from an electricity system perspective another advantage of heat pumps could be the widespread increase in electricity demand. Having a broader, more widely dispersed demand means more locally generated electricity could be used locally - reducing the curtailment of wind power and also the need for an upgraded transmission network. This in turn would facilitate a larger generation capacity into the electricity system such as wind or photovoltaic generation[Hedegaard et al., 2012][Kesicki, 2012].

Examples of electricity and heat system integration are already in existence in Denmark. Currently with the highest penetration of wind power in the world, Denmark has spent many years looking into methods of integrating renewable electricity into their extensive district heating network for a more emission-friendly energy system. Traditionally Denmark is known for its innovation and ability to set high expectations and standards in the renewable sector. With one of the longest standing emission reduction policies in the world, Denmark has set a national target of 100% renewable energy supply by 2050[The Danish Government, 2011]. To achieve this vision many papers such as; [Hedegaard et al., 2012],[Lund et al., 2014] have outlined plans to utilise large volumes of RES-E using large scale heat pumps and produce RES-H. Projects such as “From Wind Power to Heat Pumps” carried out by the Danish TSO, Energinet.dk are analysing the feasibility of such a plan[Energinet.dk, 2013], while multiple journal articles produced by public entities in Denmark also welcome the idea.

Analysis Phase 1: Ireland's Heat Sector 4

This chapter outlines the analysis carried out on Ireland's heat sector as part of the case study. Starting with the consumer choice model, this allows an insight into a wide range of consumer types and their expected choices in terms of heating systems. From this model scenarios are created based on different levels of heat pump uptake. These scenarios are analysed throughout this chapter and into the next which covers the electricity sector analysis. Once scenarios are chosen, the thermal demand needs to be changed from an annual value into an hourly demand profile for an entire year. This is carried out using an excel model which takes account of the daily average temperature through the heating degree day methodology and also some irregular events and occurrences. In creating the heat demand profile, the electricity profile is subsequently created and used as the primary source of difference between the scenarios in chapter 5. This chapter concludes with a discussion of the proposed policy change and its effects in terms of barriers, emissions, and RES-H targets.

4.1 Consumer Choice Heat Model

As explained in chapter 2, the consumer choice heat model is based on how different consumer types choose the most suited heating system to their individual needs. The model was built with detailed information regarding Ireland's housing stock, heating system data, replacement rates, present and possible future policy incentives, hidden costs, and much more data pertaining to this case study[Elementenergy, 2012a]. The heat model is a good way to test/analyse new and innovative user-defined policy incentives or supports.

In this report the end result from the consumer choice heat model is a heat pump uptake. Whether as a number, percentage or in a different format but it is only an indication of what *could* happen in each scenario. Questions could arise when reading the heat models methodology as to, 'why is the model used at all?' 'will it benefit the analysis, and how exactly?' or 'why bother add the complexity of another model on top of excel and PLEXOS models?' To answer these three questions with one word, it would be - *insight*.

The heat model ensures an insight into how consumers value different aspects of choice. Appendix 7.1 outlines the details of each of the 35 consumer types incorporated into this model. Each with different values or coefficients that derives from both 'willingness to pay' curves which were previously used in other studies on renewable heat uptake[Elementenergy and NERA, 2011] and also from a study entitled 'The growth potential for micro-generation in England, Wales and Scotland'[1] [Elementenergy, 2008]. This insight becomes extremely valuable when testing different policy decisions or supports such as; tax levies on fossil fuel (or the fossil fuel technologies); variations on electricity, fossil fuel or biomass prices; hidden costs, and many more. So the end result of the consumer choice heat model is not just a 'value', it is an understanding of how consumers react to various changes in the sector which goes a long way to mitigating institutional and technological barriers. For this reason the techno-institutional complex and choice awareness theories from chapter 2 are discussed and applied to the analysis in the latter end of this chapter, before which the scenarios and profiles are created.

High-level assumptions

In the model certain assumptions are used and can be seen in appendix 7.1. Of the assumptions the most relevant are mentioned in this paragraph.

- Regarding energy efficiency an assumption is made that in all scenarios the level of energy efficiency stated under the NEEAP plan is reached[2] and also Part L of the building regulations is fully implemented.
- The model assumes that only oil, gas and direct electric heating systems can be retired. Renewable technologies already installed are not retired as they are assumed to still be within their lifetime in 2020.
- The replacement rate of Ireland's heating systems is an assumed by the model to be 6.67% per annum, this is based on a 15 year lifetime. Consumers have the choice to change or replace the same technology.
- Heat pumps are not modelled for the industrial sector in Ireland, this decision was made by Elementenergy as there is little or no movement in this sector in Ireland.

[1] The latter is used because consumer attitude analysis towards renewable heat in Ireland was not available. There is an assumption used that Ireland's consumers would act as their English, Welsh or Scottish counterparts.

[2] See section 3.3 for more details

Scenarios

The heat model is used to create a baseline scenario that represents the business-as-usual (BAU) and two alternative scenarios. The three are listed with an explanation to follow.

- Business-as-usual (BAU)
- Night rate (NR)
- Maximum uptake (MAX)

Based upon current policy decisions and fuel projections from the World Energy Outlook 2012[3], the BAU scenario can be regarded as the conservative approach as no new policies or changes are implemented. The second scenario (NR) implements a policy change regarding the price of electricity used to operate a renewable heating system. In this scenario the price paid for electricity used for renewable heating (day or night) is set at €102.9/MWh ex.VAT[4], from 2015 until 2020. The final scenario represents the maximum uptake of heat pumps possible from the consumer model. This scenario uses extremely low electricity prices (€1/MWh) and high oil prices (€500/MWh) to encourage the max heat pump uptake (MAX). Figure 4.1 illustrates the energy input and heat output for the scenarios. Of the three scenarios, the MAX scenario is both very interesting and important. This scenario represents the maximum technological uptake that could occur from other heat pump-friendly policy incentives that are not analysed in this report. The scenarios are analysed further to ascertain the heat output which is necessary for the remainder of this chapter to create daily heat demand profiles and ultimately the electricity demand for chapter 5.

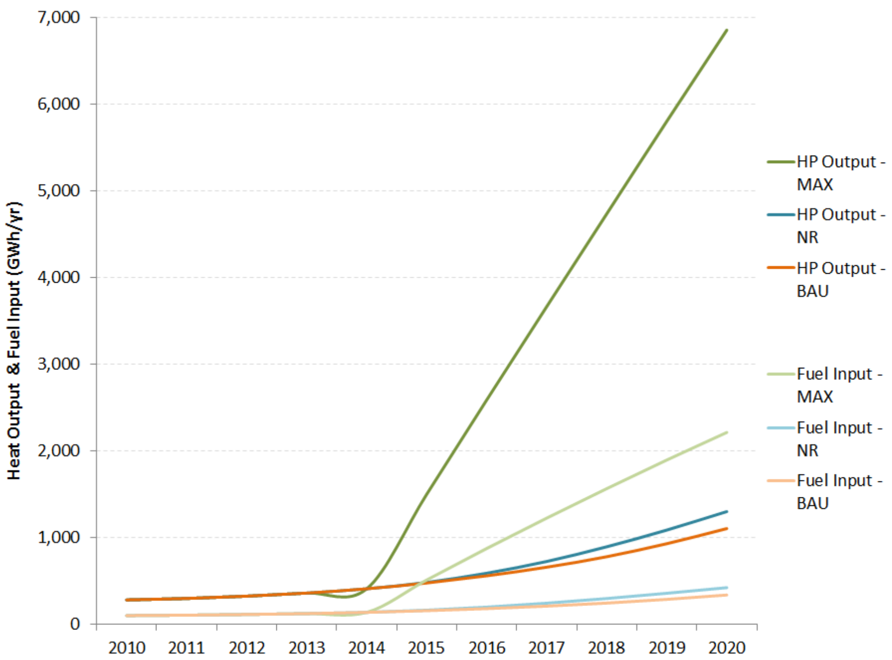

Figure 4.1: Electricity input and heat output projections for the three scenarios

[3] See appendix 7.1 for fuel prices used

[4] Current electricity night rate in Ireland[Airtricity, 2014]

Scenarios in numbers

The next step in the analysis is to disseminate the heat pump uptake by sector and technology type to represent the results of each scenario. Table 4.1 highlights the high-level results of each scenario, aspects such as the share of air sourced heat pumps used in each scenario and whether or not in the residential sector, or the expected fuel input and heat output from each scenario.

The relationship between fuel input and heat output is straight-forward and related to the share of each heat pump type and which sector they operate. For instance, a COP of 2.5 is assumed for residential size (between 9-14 kW thermal), and 3.5 for commercial size (between 42-420 kW thermal), for more details see appendix 7.1. The overall thermal demand for the system is 39.7TWh for 2020, with 18TWh in the residential, 8.5TWh in the commercial and remainder in the industrial sector.

Scenario	Heat Pump Output (GWh)	Heat Pump Electricity Input (GWh)	ASHP (GSHP) Share	Residential (Commercial) Share	Resulting SPF	No. of ASHP (GSHP) installed
BAU	1,102	334	75% (25%)	52% (48%)	3.3	73,963 (12,636)
NR	1,288	419	85% (15%)	77% (23%)	3.1	126,307 (11,159)
MAX	6,826	2,569	87% (13%)	85% (15%)	2.7	536,371 (88,087)

Table 4.1: Details of heat model scenarios in 2020

Looking at the scenarios closely uncovers an unusual occurrence that is not visible in table 4.1. In the NR scenario commercial heat pump uptake decreases while residential increases, due to lower electricity prices it is expected that both would increase. This was tracked down to the price for electricity and unfortunately this cannot be separated by technology type, meaning direct electric heating can also avail of low cost electricity in the model. This does not affect the MAX scenario as the efficiency of heat pumps outweighs the low cost of direct electric heating. It can also be seen from the table that the majority of uptake occurs in the residential sector and is air source based; this is due to lower hidden and capital costs.

Non-ETS emissions savings

When analysing the non-ETS emissions savings from the three scenarios, the various levels of heat pump uptake mean different levels of non-ETS emissions being saved. Accepting the BAU as baseline, the reduction of non-ETS savings for the NR scenario is suggested to be 146ktCO_2[5] and 1,908ktCO_2 for the MAX scenario. The suggested savings from the MAX scenario are a large amount in the context of the sector, equating to 9% of Ireland's 2020 non-ETS emissions production target. The non-ETS emissions savings along with other aspects of the analysis are revisited in the proposed policy change section 4.3 to follow but first the creation of hourly heat demand profiles is described.

[5] ktCO_2 stands for thousand tonnes of Carbon Dioxide

4.2 Excel Model - Heat Demand Profiles

This section of the report has a sole purpose, to create hourly heat demand profiles for the scenarios in section 4.1. The process is broken down into two steps, the first outlines the analytical approach, then discusses each step and assumption in the methodology. After which the platform is set to calculate and finally create hourly profiles for each scenario. This entire section is laid out so each step taken in the process of creating daily and hourly profiles are clearly explained.

The thermal and electricity demands for all scenarios has been defined in the previous section, see table 4.1 for details. To simply proportionally scale-up the electricity demand to include additional electricity used for heat pumps would be a flawed approach. As electricity has a wide range of uses, its demand profile would include everything electrically driven on the premises, making it non-scalable in this situation. Gas on the other hand is primarily used for heating and has limited usage to many other deterministic loads, for this reason the gas demand data is used to develop accurate heat demand profiles. This data was acquired from Gaslink, Ireland's gas network operator[Gaslink, 2012]. The data is for the non-daily metered (NDM) sector in 2012 whom consist of residential and small sized businesses. The data itself is daily gas usage allocations which gaslink use for each consumer. In the NDM sector the gas is mainly used for hot water and space heating requirements. This profile is used in the following sections to validate the methodology used to calculate the space heating profile and also to find the hot water requirement profile.

Space heating demand profile

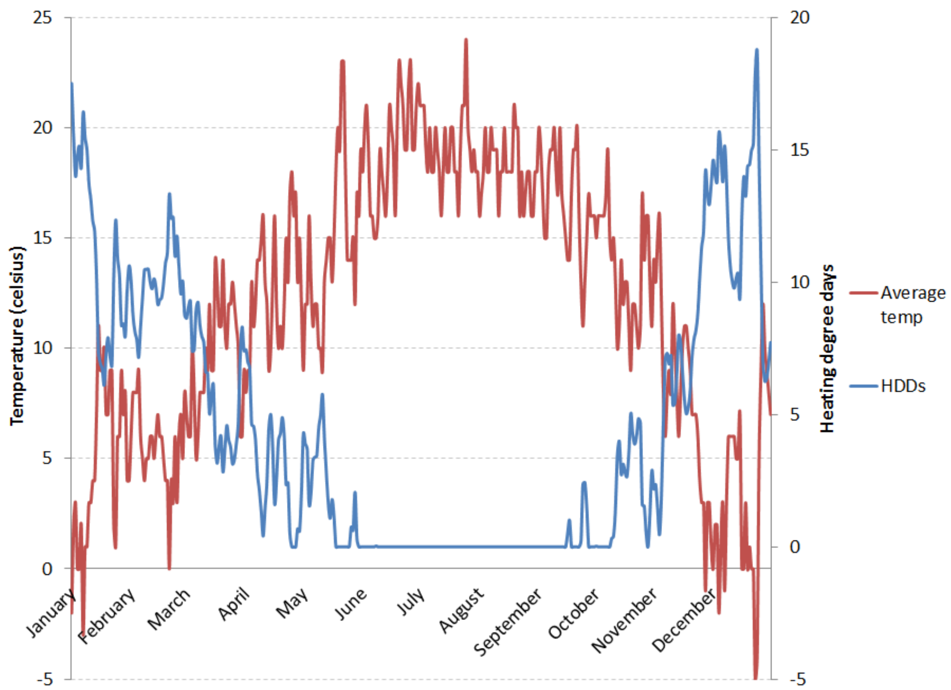

Figure 4.2: Average daily temperature and heating degree days in Ireland, 2012

Historic 2012 daily temperatures for Ireland was acquired from [ECA&D, 2014] and illustrated in figure 4.2, from which the Heating Degree Days (HDD) are calculated and also seen in the figure. HDD's are commonly used for modelling the relationship between the energy consumption of buildings and outside ambient temperature[6]. HDD measures how many (degrees) and for how long (days) the outside air temperature is below a specified baseline temperature. The baseline temperature for Ireland is assumed to be 15.5%. Both parameters are directly related to each other and have a large significance on the space heating profile as cooler temperatures result in increased HDD's and in turn effecting space heating requirements.

Occupancy, climatic and other factors

Using the HDD methodology an approximation of the daily space heating profile is found. However various aspects of the surrounding environment both internally and externally also have a bearing on the final space heating demand, holiday related occupancy patterns is a perfect example. To incorporate these unknowns into heat demand profiles, a method used by the UK National Grid called the Composite Weather Variable (CWV) is applied[UK National Grid, 2007]. CWV is a method of forecasting daily peak gas demand and load duration curves used by the UK National Grid. The external ambient temperature is corrected (or normalised) using the CWV method for 'other' factors and then in conjunction with the HDD intensity factor is used to scale into an energy demand profile. The 'other' factors used in this method consist of: effective temperatures, summer cut-off, and holiday de-rating. Formula (2) below illustrates the CWV calculation. The CWV calculations can include other factors, however it is assumed that the elements present in formula (2) cover a large percentage of unknown in the typical Irish situation.

$$CWV_{today} = Temp_{eff} * Summer\ Cut\text{-}off_{today} * De\text{-}rating_{today} \quad (2)$$

Each character in formula (2) is explained in this paragraph, starting with the effective temperature. Effective temperature is an input which dampens a particular days temperature with the previous days temperature. The summer cut-off profile is when space heating is no longer required, see figure 4.3. The summer cut-off was decided rather subjectively to account for Ireland's temperature profile. Holiday de-rating is used to allow for occupancy patterns of a dwelling over holiday periods. A holiday de-rating of 90% is used for Christmas while other holidays and weekends use a 95% de-rating. These values are based on the UK National Grid report and another example of CWV being used by [Sullivan, 2010].

[6]For more information on heating degree days see [BizEE, 2014]

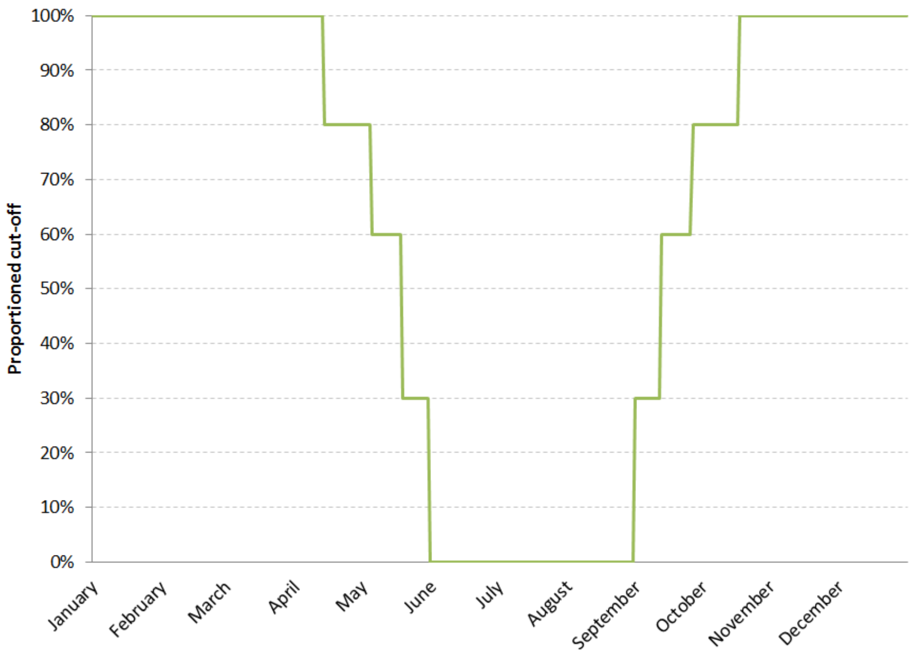

Figure 4.3: Profile of summer cut-off used for CWV methodology

Hot water requirement

The daily hot water requirement is found based on a trend from the NDM gas demand usage from Gaslink. Firstly there is three assumptions that have to be considered before the hot water requirement can be obtained; 1) the NDM gas demand profile represents mainly residential and small business users; 2) it is assumed that gas is primarily used for either space or hot water heating; 3) it is assumed that space heating is not used in summer months, in line with the summer cut-off as seen in figure 4.3. Taking account of these three assumptions it can be presumed that all gas usage in the summer months is used for hot water demand requirements and as residential hot water demand does not vary widely over the year, meaning it is presumed constant over the year. This demand along with the space heating demand are both ready to be converted into hourly heat demands.

Validation of HDD and CWV methodology

Figure 4.4 shows the HDD normalised using the CWV compared to the Gaslink NDM data. There is a causal relationship apparent between the two sets of data, as peaks and troughs in both are broadly alike and occur at similar time periods. The polynomial lines (to the order of 3) show the causal relationship between the two. This level of complexity in relation to calculating space heating requirements is decided to be sufficient for this report as taking account of 'booster' features in space heating and 'emersion' features in hot water requirements is another level of complexity that is beyond this reports remit.[7]

[7] If further detail was required on this to correlate the two closer then another element would be added to the CWV formula called up-turn which takes account of booster feature activities in very cool weather conditions.

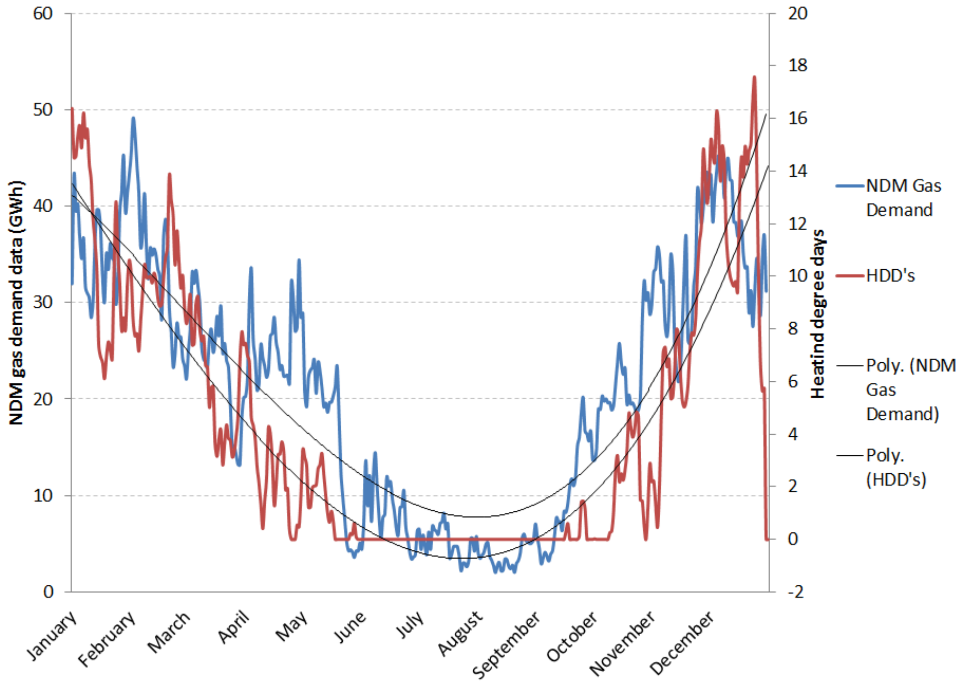

Figure 4.4: Correlation between HDD's and NDM gas demand data for 2012

Hourly heat demand profiles

At this point the daily demand profiles have been crudely identified for both hot water demand and space heating. The high resolution hourly profiles are created using data from the smart meter trials by CER and SEAI.[8] Before space heating profiles can be created, certain occupancy and the age profile assumptions of the inhabitants needed to be identified. These are influential in deciding the estimated hourly heat demand. From the 2011 census data, a weekday occupancy level of 60% was identified as a reasonable estimation for the weekday profile to account for the elderly and inhabitants who had children going to school (hence these could possibly occupy the dwelling during daytime hours). This assumption is also validated by a study on dwelling occupancy in Northern Ireland which found that approximately 60% of dwellings were occupied during daytime hours[Yohanis et al., 2006]. Other space heating demand profiles for weekends and holidays were created in the same way only these are weighted on the holiday de-rating, either 90% or 95% rather than the 60% used for weekdays. The hot water demand profile seen in figure 4.5 is taken from the aforementioned smart meter trials. Figure 4.5 also shows the weekday and weekend space heating profiles in a normalised format.

[8]These were trials carried out to assess the viability of smart meters in Ireland[CER, 2011]

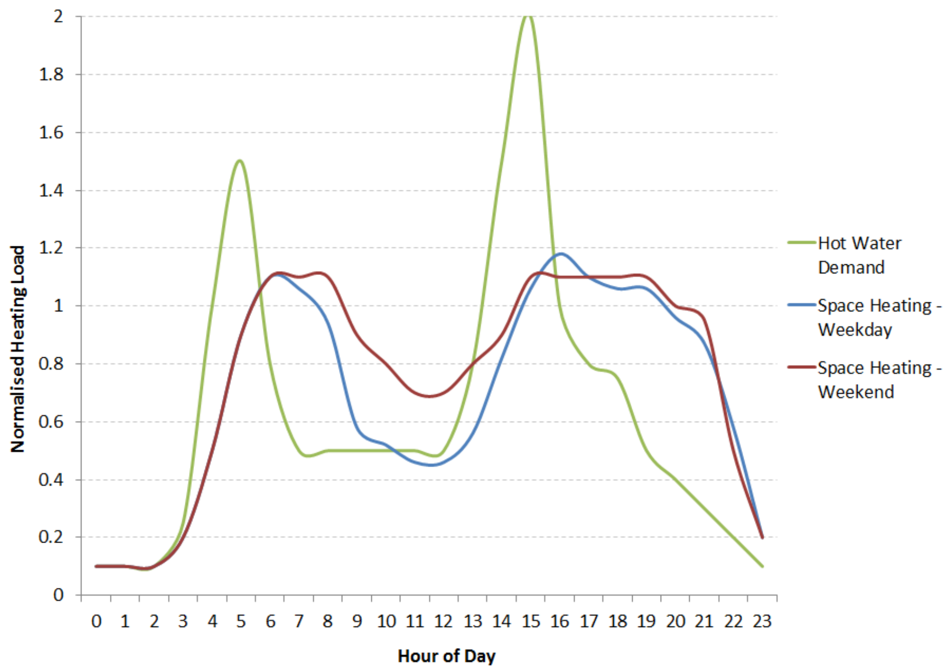

Figure 4.5: Occupancy-weighted daily space and hot water heating demand

The profiles only need the heat output information from section 4.1 to scale the profiles up to the desired thermal demand for the scenario profiles to be complete. The thermal and electricity demands shown in table 4.1 were used as guides for the excel model to create the hourly load profiles. After the entire analytical process of accounting for the obvious and not-so-obvious aspects of a heat demand the following figure 4.6 illustrates the additional demand in terms of daily electricity usage in four different months of the year.

The excel model created can take multiple different aspects into account such as forecasted residential fuel usage or the seasonal efficiency of other more conventional heating systems. The majority of these features are not necessary because the fuel input and heat output are known, this removes the need for complex calculations. The inner workings of the model are not explained in detail as it is felt this report is focused on the effects on the electricity system. The resulting heat (and electricity) demand from this chapter is created from the daily demand from section 4.1, then using a simplistic excel model these are converted into hourly demand that are based upon empirical data from the smart meter trials. The resulting electricity demand is vital for the following chapter and it is felt that these profiles represent realistic demands in each respective scenario.

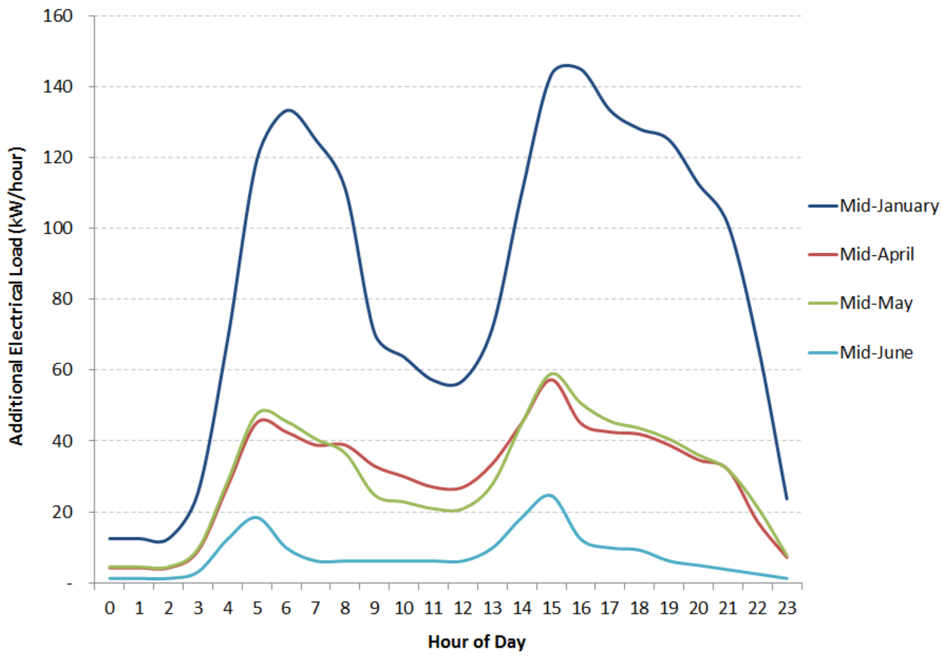

Figure 4.6: Daily additional electricity demand in four different months of the year

4.3 Proposed Policy Change

"...the pursuit of policy in the face of happiness" - Barbara W. Tuchman[9]

This chapter is focused on analysing the concrete technical alternative set forth in an attempt to increase renewable heat. This is the first step of Lund's Choice Awareness theory where an alternative or alternatives (the more the better) are outlined and analysed to ascertain the feasibility of each. To enhance the feasibility of the alternative in this report a policy change is proposed which involves all electricity used for renewable heat to be purchased at night rate, €102.9/MWh ex.VAT. The change as seen from figure 4.1 has an effect on the uptake of heat pumps. As pointed out by [Connolly and Mathiesen, 2014], it can often be difficult to detach the optimal outcome from vested interests. Energy providers could be disgruntled over such a proposal due to the financial losses they would incur. However this could possibly be avoided through governmental intervention to curb the losses, whether through the PSO or through other means. If this policy change was implemented in 2015, the economic fallout is estimated to be in the region of €12 million for 2020.[10] This is a relatively small amount in comparison to the overall billion euro business of energy supply in Ireland.

The main benefit of using the consumer choice heat model is the insight into consumer choices and how support mechanisms can alter trends. For instance table 4.1 highlights the change in

[9] Source:[Tuchman, 1985]

[10] Using the difference between night rates and 2020 day rates, multiplied by the difference in electricity used for heat pumps in the BAU and NR scenarios. This is calculated assuming all electricity used for heat pumps in the BAU scenario is on day rate, hence making the result a worst case scenario.

one scenario versus another. From the table it is found that implementing the night rate policy change will have a positive effect on the uptake of air source heat pumps in the residential sector as the heat output doubles, whereas there is little or no increase in ground source heat pumps. This is down to the coefficients put on different aspects of installing and operating a heat pump such as hidden and capital costs. This insight and knowledge can be used to target areas within a sector, for example if urban dwellings using oil-fired central heating systems were the target consumers that a particular policy was seeking to affect then this model could give an insight into the effects from various supports. This feature of the heat model is used in this report to outline how many air source versus ground source heat pumps were used and also the residential and commercial split. However the feature could be used to greater effect than has been done in this report, especially if a variety of regulatory measures were being analysed to show greater effects on certain areas of the heat sector demographic.

Implementing this policy change could be seen as taking a continuity approach in term of the theoretical concept; techno-institutional complex. By using the night-rate price for all electrically operated RE heat technologies, it creates a smooth transition, lessening the perceived gap between conventional heating systems and alternative options in a similar way to the Edison example from chapter 2. This small but significant step could alter the basis for heating systems in Ireland, increasing heat pump uptake and renewable heat share, while decreasing non-ETS emissions and finally giving choice back to the consumer. All this could be possible through a straight-forward regulatory change which lowers the financial strain (in terms of operating expense) of heat pumps on consumers. Using a purchase-agreement style idea in Ireland such as fixed NR electricity price for renewable heat technologies could have many more benefits than outlined in any table or graph in this report. As previously mentioned in chapter 3, the technology in a standard heat pump is increasing at such rapid rates that dispatchable, flexible capacity is a near-future possibility in Ireland. This transition is more dependent on system adaption and development rather than technological advancement.

The lack of top-level buy in is one of the main barriers found in analysing Ireland's heat sector. There is a severe lack of policy support by the government and other institutions for RES-H targets to be met. Due to the diffuse nature of the heat sector, one scheme or policy incentive will not help all areas. However starting and stopping support schemes as outlined in section 3.1 is not the way forward either. Long term commitment is essential for security of an investment; this is the necessary step to encourage both suppliers to invest in a supply chain and also for consumers to change from conventional systems. By implementing a night-rate policy for electrically driven renewable heating systems, a step on a long road to reaching the targets is taken. As previously mentioned this policy change would only cost €12 million in terms of lost revenue to providers from electricity charges in 2020, but non-ETS emissions would be down, RES-H levels up and Ireland would have more options looking ahead in terms of paths to a sustainable future.

Analysis Phase 2: Ireland's Electricity Sector 5

This chapter analyses Ireland's electricity sector using PLEXOS software for modelling power systems. The model was created specifically for the All-island electricity system and includes detailed information on all aspects of the system for both for Ireland's and Northern Ireland's systems. It was necessary to model the All-island system rather than just Ireland's for accurate representation of the SEM, which acts as one market in reality. Otherwise cross-border trading between both jurisdictions would cause issues that could undermine the entire objective and result. The outcome of this model is to show the effect of additional electricity demand from increased use of heat pumps as discussed in the previous chapter. The PLEXOS model is based on a 2020 scenario that successfully reaching its 40% RES-E target in compliance with the Directive.

The scenarios in chapter 4 were created based on different levels of heat pump uptake. This in turn results in different levels of electricity demand which are analysed in this chapter to show the effects on the system. The EU Directive regards the output from heat pumps to be renewable, with one caveat. The caveat surrounds the efficiency of the electricity system that provides the heat pump with electricity. The ratio of total final energy consumption divided by total primary energy consumption means only a certain amount of the heat produced from heat pumps can be attributable to RES-H. In an electricity system with 40+% renewables, the input/output efficiency should be much higher, resulting in more renewable heat from the same input energy. This calculation is carried out using the methodology outlined in Annex VII of the Directive and can be seen in the latter stages of this chapter. Figure 5.1 gives a brief overview of the entire system that is modelled and analysed in this chapter.

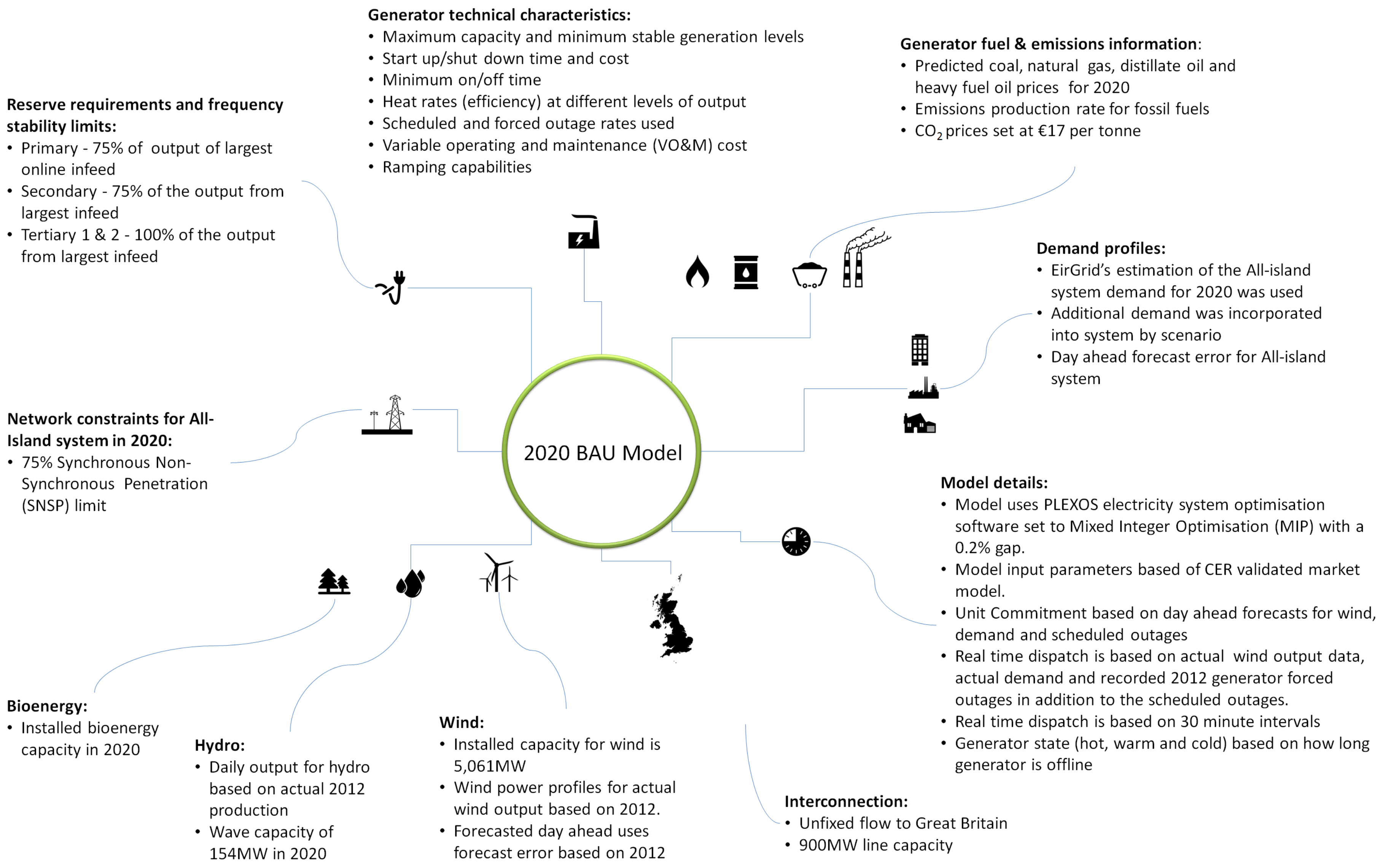

Figure 5.1: System overview with main assumptions used for modelling.

5.1 PLEXOS Model

The PLEXOS model is created using advanced features of the software for accurate simulations and solutions. Detailed information on generators, interconnectors, reserves, and regions used in the model are included in this section and an overview of the system modelled can be seen in figure 5.1. The level of complexity in the model increases substantially when variables and uncertainties such as the stochastic nature of wind power, system demand fluctuations and forced outages are taken into account. These are incorporated into the model using a rolling 24-hour unit commitment which dispatches the most economically feasible generators 24 hours ahead based on system demand and wind forecasts. Another model interleaved with the first receives the unit commitment - re-dispatchment of generation plant based actual wind and system demand profiles, and forced outages is then carried out. In the model a forecast error is used based on 2012 data, in a similar way to the demand forecast error. A 6-hour look ahead is also used in all models, this cannot foresee forced outages. Using this simulation strategy, the model simulation gives an accurate insight into the ramping and cycling required by thermal plants to maintain a safe, stable, and balanced electricity system. This ability will be essential when analysed the effects of an extra demand on the system later in this report.

Initially the model was created using 2012 All-island information for calibration purposes, using a similar method to that used by [Clancy and Gaffney, 2014]. Once calibrated to the actual 2012 dispatch, the necessary changes were made, upgrading the constraints, generators and system demand to match the expected 2020 scenario from EirGrid's Generation Capacity Statement 2013 - 2022. All details of the calibration process can be seen in appendix 7.2. The next step of this chapter outlines all assumptions used in the electricity model with an overview of the system. Figure 5.1 shows some of the main assumptions and an overview of the entire system modelled.

Assumptions

Fuel and carbon prices shown in table 5.1 are used for modelling the All-island electricity system in 2020. The fuel prices along with the ETS price used during simulation (€17 per tonne) are identical to the values used in the SEAI Energy Forecast model to 2020 report[SEAI, 2013a], originating from the World Energy Outlook 2012.[1]

Fuel Type	Price (€/GJ)	Start Fuel Type	Price (€/GJ)
Gas (NCV)	8.10	**MP Start**	8.43
Coal	3.31	**Tarbert 1,2 Start**	16.58
Distillate	19.30	**Tarbert 3, 4 Start**	16.18
Oil	14.84		
Peat	4.27	**ETS Carbon Price**	€17/tonne

Table 5.1: Fuel and CO_2 prices used in electricity model

[1] Transport costs were not added to the fuel prices. As fuel prices are speculative this paper surmised that an addition 1-2% would not have any significant effect on the results.

Generation and interconnection capacities used in the PLEXOS model can be seen in figure 5.2. These capacities are estimated by the system operator for each year up to 2020. It is estimated that the system will contain in excess of 8GW of thermal generation, nearly 6GW of renewable generation (of which 5GW will be wind power), two interconnectors to Great Britain (GB) with a total capacity of 750MW and one pumped hydro storage plant of 292MW.[Eirgrid, 2013a] As the All-island electricity system is relatively isolated with limited interconnection capacity, the profile of generation capacity as seen in figure 5.2 reflects this isolation with high levels of gas generation to ensure system flexibility. Pumped hydro storage and interconnection also increase system flexibility.

Electricity trading with Great Britain's (GB) electricity system is unfixed and only limited by the line capacities. The GB system consists of one large CCGT gas turbine (1,800MW) which sets the SMP in the GB system. Trading will occur between the regions due to differences in SMP's and the addition wheeling charges applicable to the interconnectors. There is also a 1,100MW load in the GB system to ensure that not all the electricity generated is exported. Information on modelling the future interaction through the two interconnectors to GB is inspired from the CER forecast model[CER, 2012a].

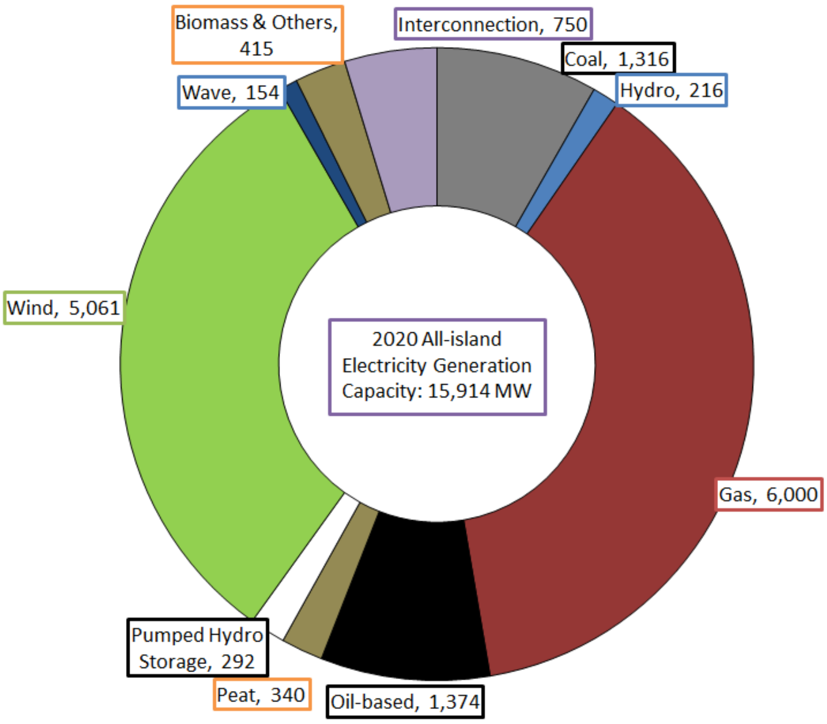

Figure 5.2: All-island electricity generation capacities, 2020

Baseload generation in the All-island system is mostly delivered by both coal and peat-fired plants. The system operator indicates in the 'Generation Capacity Statement' that peat-fired capacity will still be available in 2020 but the report suggests it will not generate. The majority of the peat-fired capacity will then go unused in all modelling simulations, the exception is the Edenderry plant which is expected to be 30% co-firing by this time.[Eirgrid, 2013a]

System demand and wind generation profiles are created using a similar method in the PLEXOS software - both are extrapolated from historic data in conjunction with the predicted system demand and wind power capacity creating 2020 profiles. Using the base year of 2012 to represent an average temperature year, the demand and wind generation data is taken from this year and projected using a feature in-built in PLEXOS. The system operator expects the 2020 All-island system demand to be in the region of 40TWh and for wind power capacity to be approximately 5GW[Eirgrid, 2013a]. The additional demand deriving from the heat sector analysis in chapter 4 varies by scenario and can be seen in figure 5.3.

Scheduled maintenance and forced outages are taken into account during modelling. As this report is simulating in 2020, the maintenance schedule is unknown at this time. To account for outages in the model, maintenance and forced outage rates for each plant are used which derive from the Commission for Energy Regulation (CER) validation model[CER, 2012a]. These rates are used by PLEXOS to randomly select when a plant is off-line for maintenance or forced outage. This is carried out using a feature called Projected Assessment of System Adequacy (PASA), which can use a range of distribution algorithms to calculate the most efficient time to carry out maintenance, i.e. when demand is low and other large plants are not out for maintenance during the same period.

Constraints. The model assumes that all present day system constraints are removed in a 2020 system. This is a result of the system operator's intervention with the previously mentioned DS3 and Grid 25 plans. Both plans concentrate on making the All-island electricity system a more sustainable and secure system. Grid 25 focuses on expanding the national electricity network infrastructure to reduce bottlenecks through increasing transmission capabilities throughout the system. The transmission upgrade will allow the system non-synchronous penetration (SNSP) limit to rise from 50% to a predicted level of 75% in 2020[Eirgrid, 2011]. The SNSP is implemented to ensure system stability at times of high levels of variable generation such as wind power. In 2020 the SNSP constraint ensures that no more than 75% of the system demand can be served from non-synchronous services, which accounts for both interconnectors to Great Britain and variable renewable generation. Formula (3) represents the SNSP methodology.

SNSP = (Variable generation + imports) / (System load + exports) (3)

Ancillary services (also known as reserves) ensure the electricity system maintains security and stability. Reserves provide cover for an unexpected change in demand or sudden drop in generation output due to a unit breakdown for example. Ireland's operating reserve protocol requires four classes of reserve: primary, secondary, tertiary 1 and tertiary 2. The size of these reserves requirements is dependent on the largest in-feed in the system at the particular time. There are also different time response requirements for each of the four classes of reserves, primary start within 5 seconds and tertiary 2 by 15 minutes. The percentage of the largest in-feed to be covered can also vary between classes, 75% for primary and secondary, 100% for the tertiary reserves. Details of reserve information used in the model is available in the 'Operational Constraints Update 2012'[Eirgrid, 2013b].

Scenarios

The scenarios have been chosen in chapter 4. This chapter analyses the effects of the extra demand on the All-island electricity system. The three scenario will be referred to as the same names in the previous chapter; BAU, NR, and MAX. The additional electricity demand for each can be seen in annual format in table 4.1 or graphically in figure 5.3 where scenarios are shown in an hourly demand profile for 2020. The additional demand from both BAU and NR scenarios is small but is analysed to show effects (if any) on the system. For the MAX scenario the system demand increases by 6.4% or 2,569GWh. The extra demand is incorporated into the model using the same methodology as the base demand for the actual and forecast models. Both are in 30 minute time resolutions.

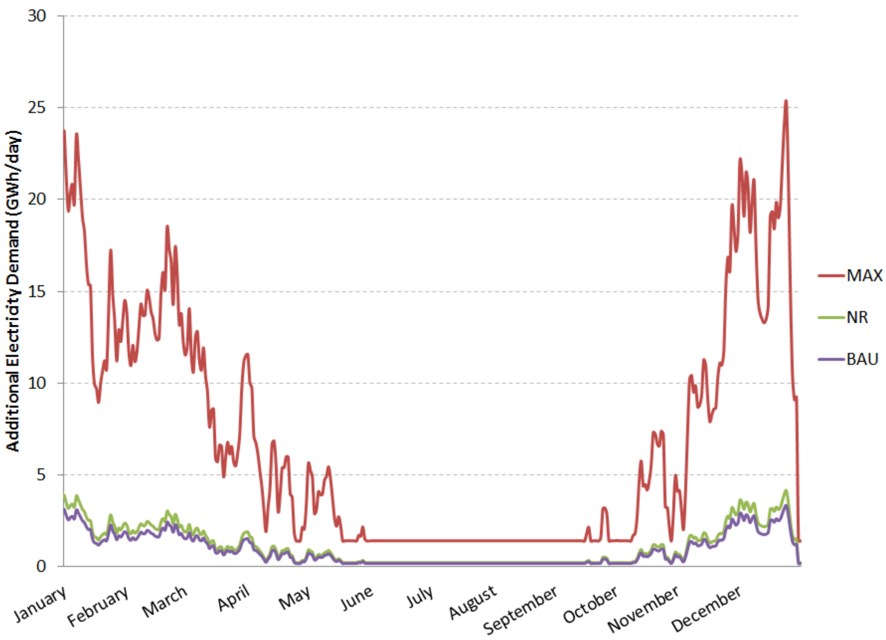

Figure 5.3: Extra electricity demand from heat pumps on the All-island electricity system

5.2 Electricity System Analysis

To start this section an overview of the generation dispatch is shown to give an insight into the demand profile and also to outline the share each fuel type (or technology in some cases) contributes to the system demand, see figure 5.4 for details. It can be seen from the figure that in each quarter the generation is not the same due to variation in system demand. One of the first things to notice is the contribution of renewable energy to meet system demand. In the BAU scenario, wind energy contributes 34% to the renewable target, others such as landfill, CHP, biomass and biogas altogether represent 7% and wave has a 1% share - this means Ireland fulfils their RES-E target of 40%. No additional renewable capacity is necessary to stay in compliance with the RES-E target in the alternative scenarios.

At this stage of the analysis before going deep into the details of the model, it is reiterated that all generation capacities used in the dispatch model are published values from the system operators[Eirgrid, 2013a]. This point is highlighted because in terms of wave energy, 154MW in the All-island system by 2020 is extremely unlikely as there is currently no commercial generation from wave or tidal in the Irish system.

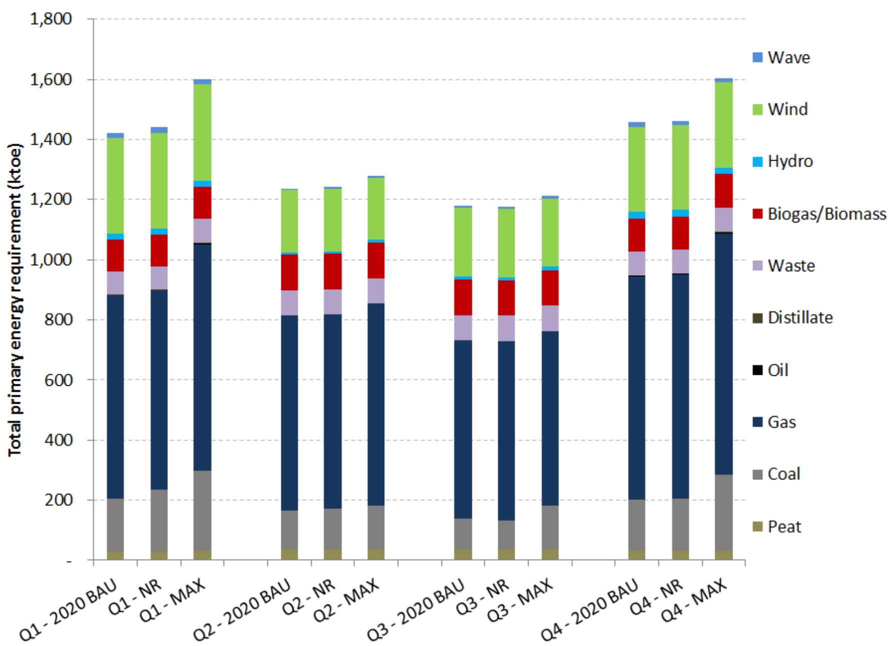

Figure 5.4: All-island electricity system quarterly primary energy requirements for each scenario

Fossil fuel offtake and related CO_2 emissions

Figure 5.5 highlights the fossil fuel offtake and CO_2 emissions from each of the three scenarios. The figure gives an insight into the increase of each with the extra demand on the system. From the figure, a first insight is given into the suggested CO_2 emissions level in 2020 if all assumptions such as meeting the 40% renewables target and others surrounding generation capacities are met. Following this figure 5.6 shows the extra fuel offtake used and CO_2 emissions released as a result of increased electricity demand.

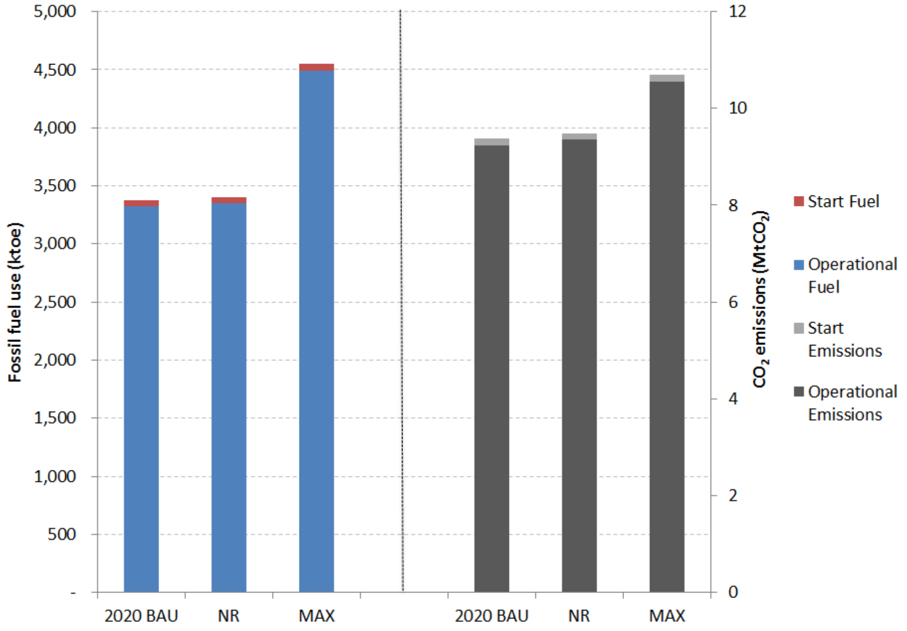

Figure 5.5: All-island electricity system fossil fuel offtake and CO_2 emissions for each 2020 scenario

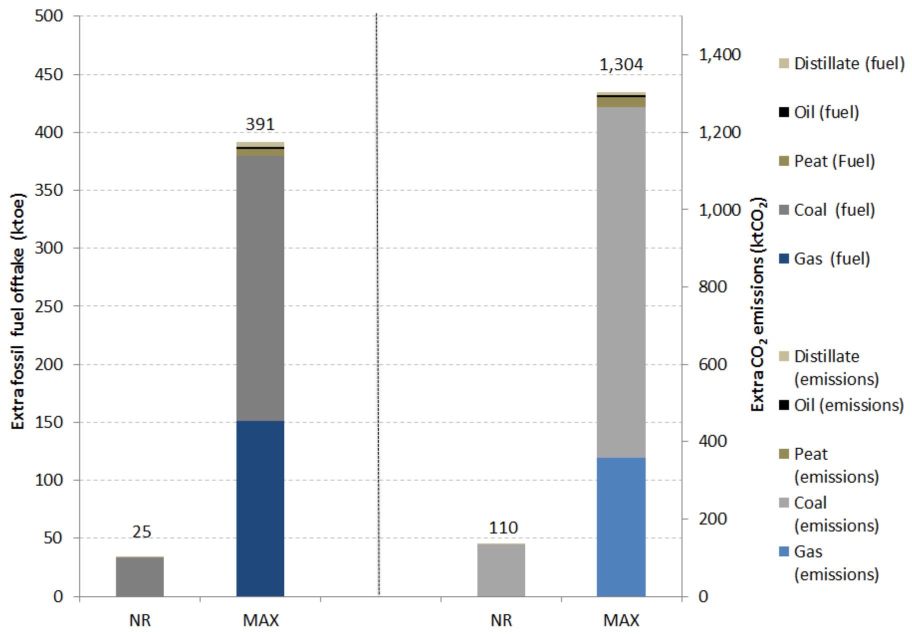

Figure 5.6: The extra fossil fuel and CO_2 emissions for the alternative scenarios (NR and MAX)

From figure 5.6 the main fossil fuel offtake increases in the MAX scenario are from coal (57%) and gas (42%), with the CO_2 emissions for coal increasing by 68% and 30% for gas. The large increase in coal offtake rather than gas is mainly due to the carbon price being used, €17/ton of CO_2.[2] Coal only contributes 6% to the overall system generation in the BAU scenario and 8.5% in the MAX scenario (compared to 20% in 2012). With the capacity offline, coal-fired generation becomes more economically viable when the extra demand is added and the SMP increases. This point is illustrated using figure 5.7 which shows the online capacity factor from all fossil fuel generation types in the model increasing with the additional demand from the MAX scenario. This means that units are operating at higher load points, which is necessary to meet demand.

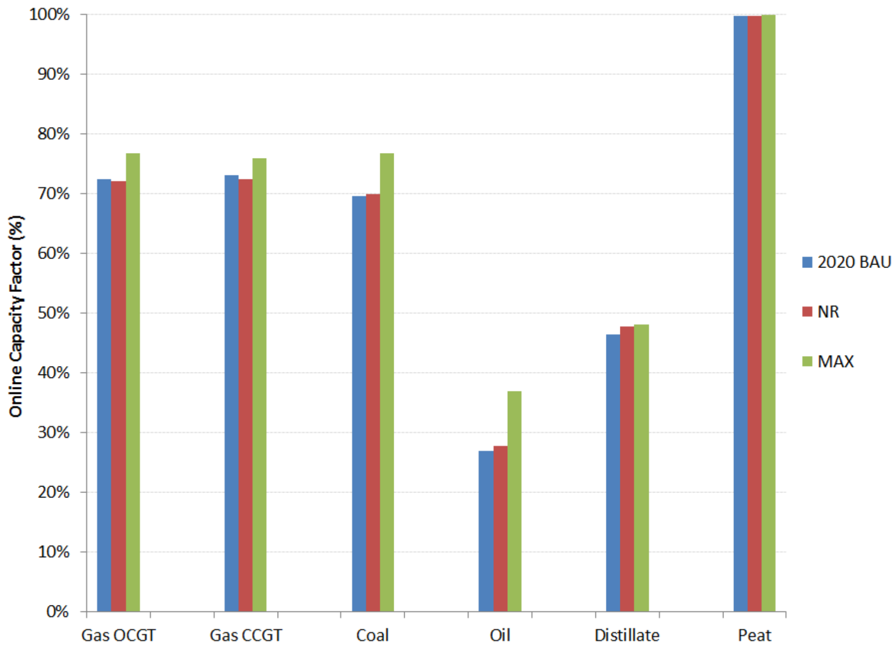

Figure 5.7: Online capacity factor for each of the fossil fuel generation types

CO_2 emissions intensity

Figure 5.8 introduces the concept of emissions intensity, or CO_2 emissions per MWh of output. The figure illustrates both the emissions intensities for fossil fuel based generation only (left) and the overall system generation (right). From the fossil fuel based generation emissions it can be seen that the intensity increases with more demand, this is directly related to the extra ramping of emission-intensive fuels such as coal and peat being utilised more frequently. From the overall system emissions, the BAU scenario CO_2 intensity suggested by the model is 0.281tCO_2/MWh, a reduction of 39% from 2012 levels. The affect from additional demand without increasing renewable capacity accordingly means the extra demand needs is met by fossil fuel based generation. This has the effect of increasing the overall electricity system emission intensity in the MAX scenario by 8%, to just under 0.28 tCO_2/MWh.

At this stage of the analysis section, a high level insight into the simulation results has been illustrated through the following graphs; quarterly primary energy requirement profile, annual

[2] See sensitivity analysis section 5.2 for further details on the effects of the predicted carbon price on generation versus the current carbon price

fuel offtake and resulting emissions, the effect of additional demand on the concepts of online capacity factor, and finally emissions intensity. From this point onwards an in-depth look into the system characteristics including information on ramping, units starts, and additional costs is discussed.

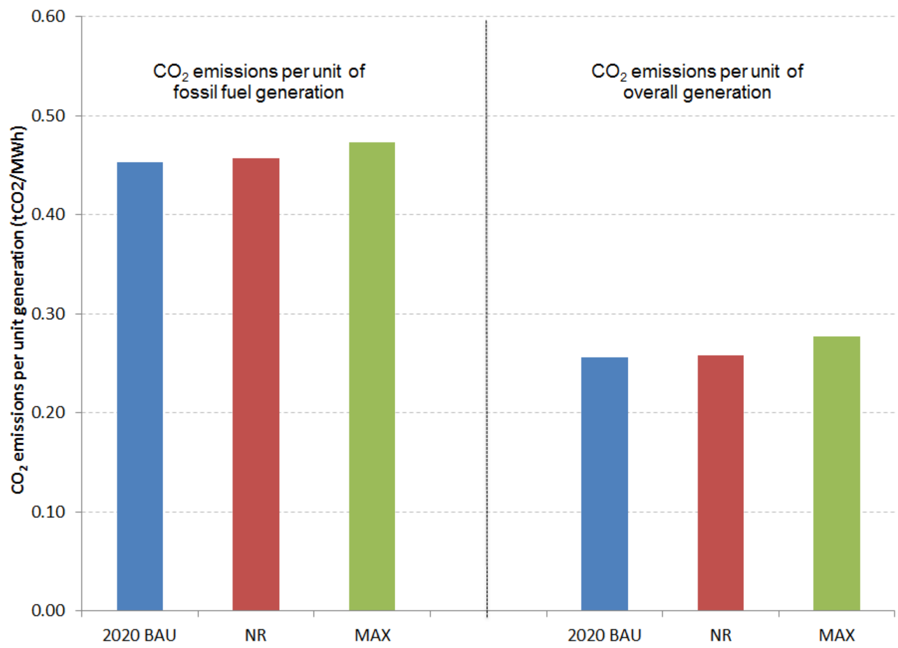

Figure 5.8: CO_2 emissions intensity from the fossil fuel units (left) and entire All-island electricity system (right)

Effects on unit dispatch and system operational strategy

As previously mentioned, the All-island electricity system contains high levels of gas-fired generation due to the flexible characteristics they add to the system. In a system such as the All-island system with high levels of stochastic renewables and other variables, ensuring a stable, secure electricity system is a big issue, one that gas generation negates through its ability to ramp quickly and on demand. For this reason, ramping requirements is identified as a fundamental concern with increasing system demand.

A significant worry behind ramping is the effect on the generator units themselves. It has been found that increased ramping and cycling causes thermal stresses that can lead to premature failure in some cases. The following two figures 5.9 and 5.10 highlight the change in ramping intensity experienced during simulations carried out for each scenario.[3] Ramping intensity is the amount of ramping activity in a time period (MW/min). Figure 5.9 illustrates the ramp up intensity while figure 5.10 shows the ramp down intensity experienced. It can be seen that between the BAU and MAX scenarios ramping increases in each figure for both Gas OCGT and Gas CCGT. All other categories in the figures either stay relatively constant or even reduce.

[3] Peat-fired generation is not illustrated as it does not change in any scenario

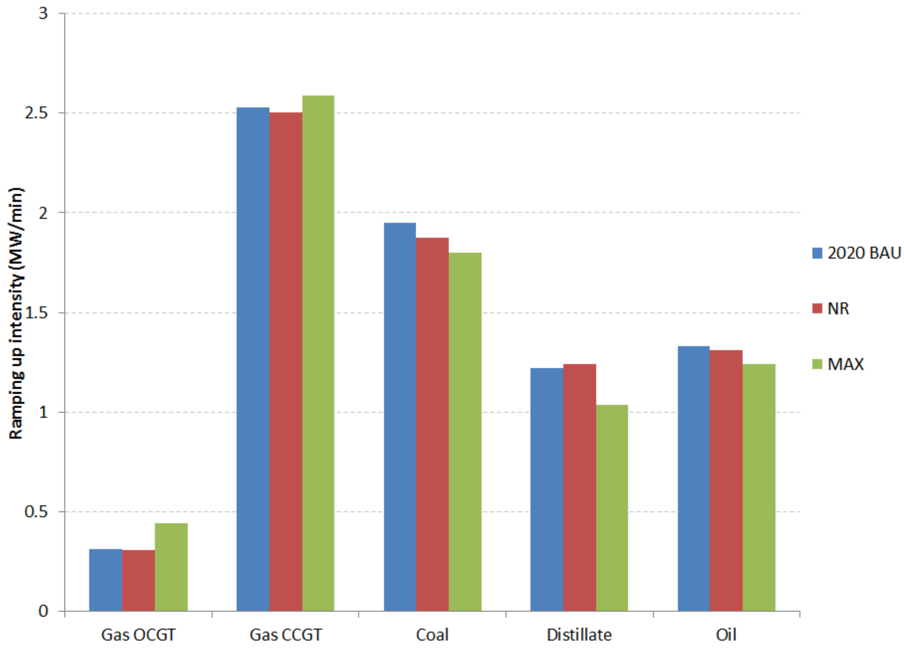

Figure 5.9: Ramping up intensity of each fossil fuel generation type

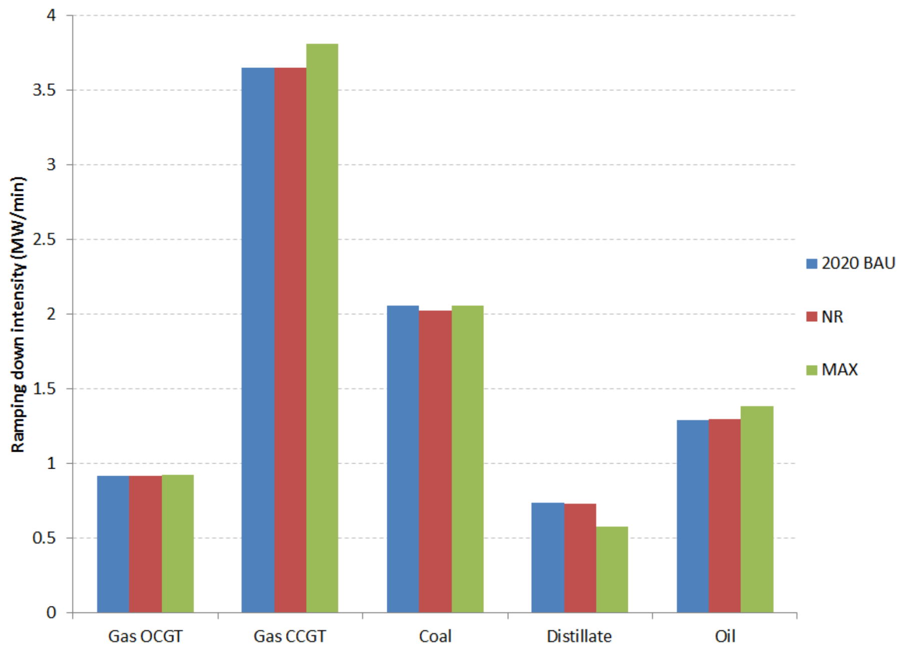

Figure 5.10: Ramping down intensity of each fossil fuel generation type

It was found intriguing that some generation categories reduce their ramping intensity so the total ramping intensity figure 5.11 was created to show the overall effect on each scenario. The figure highlights the ramping effects for each scenario and concludes that the 'bottom' line effect is a *lower* ramp intensity with the additional demand. The MAX scenario experiences 1.4% less ramping in 2020 compared to the BAU equivalent. Considering this difference is for the maximum uptake of heat pumps in Ireland and the ramping difference is only minuscule, thus making is negligible.

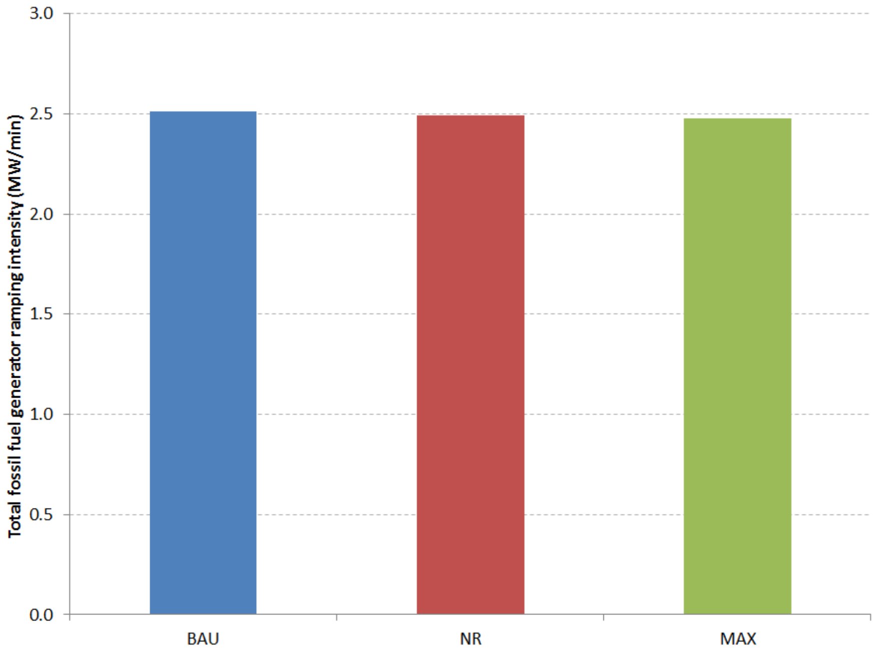

Figure 5.11: Total ramping intensity of fossil fuel generators by scenario

Looking further into the result of figure 5.11, the number of fossil fuel start-ups and the average time the units were online was investigated. Figure 5.12 shows both of these aspects, the primary y-axis shows the average number of hours a fossil fuel unit was online with each start. The secondary y-axis illustrates the number of fossil fuel starts for each scenario in 2020. From this figure it can be seen that fossil fuel units are on for longer in the BAU towards the MAX scenario. It also shows the number of unit starts is lowest in that scenario. This implies that even though there is less ramping intensity, there is more units starting and ramping at lower rates. This results in a 10% increase in start energy between BAU and MAX from 54.8 to 60.5 ktoe. An additional €8 million in generator start and shutdown costs is the monetary fallout.[4]

This phenomenon has stemmed from the increased system demand, but when this paper looked deeper it found the requirement to provide four classes of ancillary services was a key factor. In the MAX scenario, extra units are brought online to meet demand but also ensuring reserve requirements of all ancillary service classes are met. For example; gas units provide approximately 9TWh of reserve in the BAU scenario, with additional demand in the MAX scenario this reduces by 3%. This vacancy is mainly taken up by coal units.

[4]This value excludes the added fuel costs

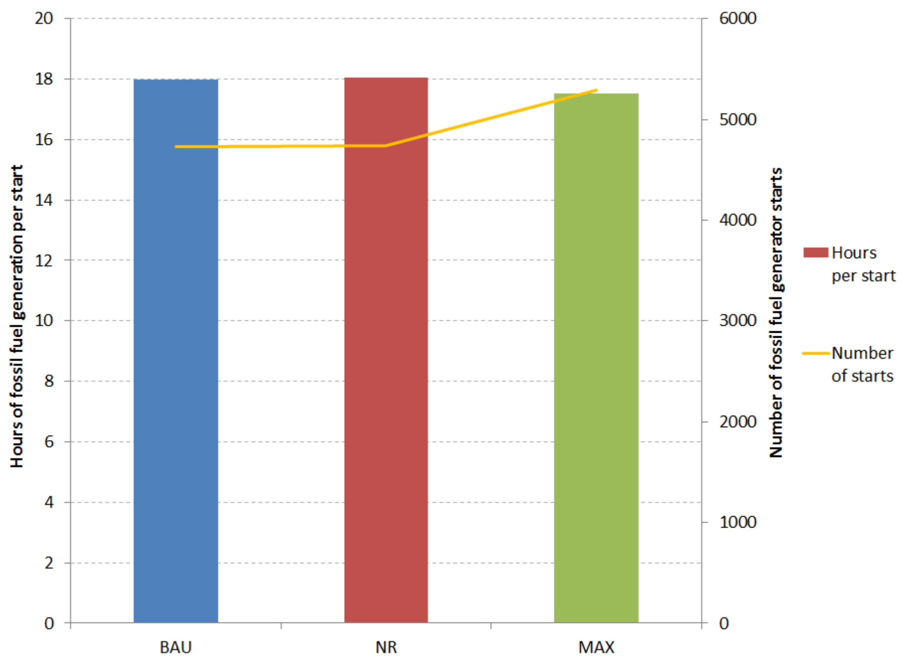

Figure 5.12: Total hours generating per start for fossil fuel generators by scenario

Effects on the other types of generation

As this point in the analysis, the fossil fuel based generation has been dissected but the rest of the generation portfolio has not. These will be addressed in the following bullet points -

- Hydro and 'other' renewable generation which includes landfill, biogas/biomass and waste, all stay constant and are not affected by increased demand. These capacities already operate at the optimal capacity when available.
- Pumped hydro storage increases generation from 339 to 347GWh between the BAU and MAX scenarios. This generation capacity is nearly utilised fully every day in the BAU scenario so it can only increase generation marginally.
- Wind and wave generate as their respective profiles allow. There is no curtailment in any scenario in this report due to the constraint-free system and the SNSP limit of 75%.

Bilateral electricity trading

The trading aspect of this report had been a constant issue throughout the analysis. Questions of capacities, GB load, should there be line restrictions or not? what is the likely trade flow in 2020? Issues surrounding these questions can cause uncertainty in a modelling and methodological approach. Assumptions were made to move forward with the analysis and in the end the future is unknown as to which way the trade is expected to flow. Only knowledge, historical patterns and experience can help to use feasible assumptions. The capacity, load and wheeling charges for GB were set by the CER in a 2020 forecast model recently published which made the situation easier to manage.

In the BAU the net line flow is -4.4TWh to the GB system, in other words the All-island is a net importer. This increases by 7% in the MAX scenario. This paper does not see this import as an issue because; 1) the analysis is on the system's ability to cope with extra demand with a focus on the generator units capability for ramping and 2) the bilateral trading with the GB system has historically been import in terms of electricity, for instance there was 2.2TWh of electricity imported to the All-island system in 2012, using only one interconnector with a max import capacity of 450MW, the second only came online for the last 2 months of the year. In the 2020 scenario the assumption used in relation to line capacity is 900MW, much larger than 2012.

Additional system costs

The result of additional demand up to this point has changed operational strategy insofar as more units are online but not for as long as in the BAU scenario. In terms of the financial fallout, the NR scenario adds €4 million in total generation cost, which consists of generation, emissions, abatement and start and shutdown costs for the year. For the MAX scenario this cost rises to €117 million for the same period. The majority of this (over 75%) is accountable to generation costs which are variable costs attributable to the generation of electricity.

Calculating the renewable contribution from heat pumps

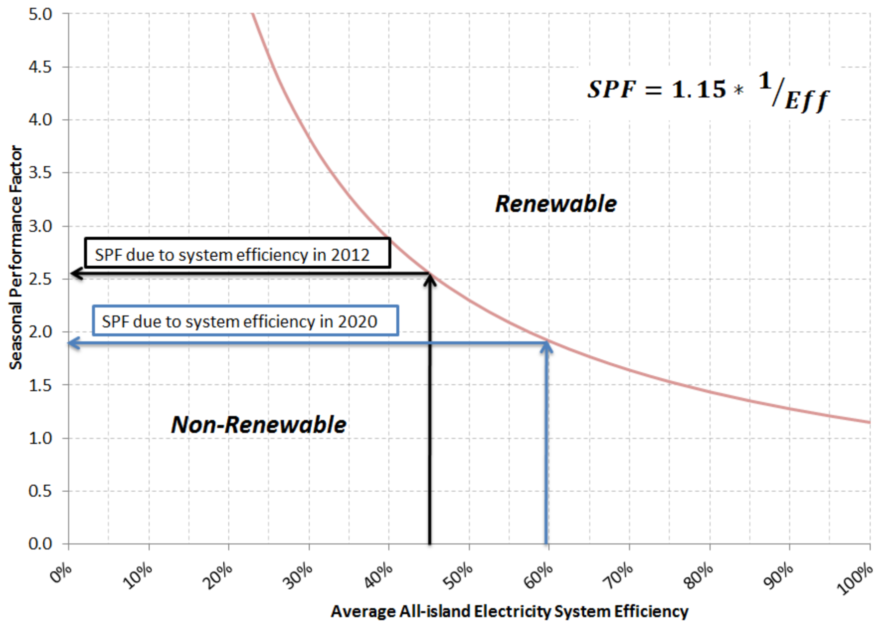

Figure 5.13: Seasonal performance factor curve based on formula in Annex VII of the Directive to indicate if the output from a heat pump is counted as renewable heat

As previously mentioned there is a stipulation in the Directive in relation to heat pumps and their status as being renewable. This issue is addressed here to ascertain the amount of heat output (if any) from chapter 4 is considered renewable and can contribute to reaching the RES-H target. Figure 5.13 is created using the formula set out in Annex VII of the Directive in relation to calculate this caveat, which can be seen in the figure. The figure shows a curved line that indicates the seasonal performance factor which is the boundary for renewable and non-renewable heat pump output. In the 2020 scenarios the system efficiency is 59% and using the formula as seen in figure 5.13 the SPF limit for what is renewable or not is 1.95. This is used in table 5.2 to calculate the renewable heat output from each scenario. The table also shows the total electricity input and heat output from each scenario in chapter 4. Using the SPF value calculated above the non-renewable and renewable heat output is found. USing the BAU scenario as an example, there is 335GWh of electricity used which is multipled by the SPF value calculated using the formula from the Directive (1.95) equalling 653GWh, which is the amount of heat from the heat pumps that is not regarded as non-renewable heat. All heat produced in excess of this value is regarded under the Directive as renewable. The overall heat production in that scenario is 1,102GWh so the renewable heat contribution of 449GWh.

Scenario	Total Electricity Input (GWh)	Total Heat Output (GWh)	Non-Renewable Heat (GWh)	Renewable Heat (GWh)	Contribution to RES-H
BAU	335	1,102	653	449	1.1%
NR	419	1,288	817	471	1.4%
MAX	2,569	6,826	5,010	1,817	4.6%

Table 5.2: Total heat output by scenario divided into non-renewable and renewable

The BAU scenario provides 1,102GWh of heat to consumers and of that 450GWh contributes to the RES-H target which is the equivalent of 1.1%. The NR scenario is similar with higher outputs in each category. The MAX scenario provides nearly 6,826GWh of heat and 1,817 of which is renewable. This scenario contributes 4.6% towards the RES-H target of 12%.

Sensitivity Analysis

This section is included to delve a little deeper into two areas of the electricity system analysis. The areas are chosen as it is felt that the report would benefit from a deeper understanding of their influence or the effects from each. The areas analysed are in relation to; SNSP limit and carbon prices.

Sensitivity No.1 - SNSP limit

The effects of the SNSP limit on wind and wave power and their curtailment is analysed to witness whether different levels of SNSP affect the output from each. In this report there is no curtailment of wind or wave using a 75% SNSP. This limit is lowered to current levels at 50% and both the BAU and MAX scenarios are simulated.

In the 50% SNSP-BAU scenario there is curtailment of wind, 4% or 435GWh. When the additional load is added in the MAX scenario this curtailment lowers to 3% and the constraints are binding 106 hours less over the year. From this analysis it can be concluded that higher demand can lower curtailment, helping to facilitate more renewables in the electricity system.

Sensitivity No.2 - carbon price

The effects of different carbon dioxide prices is analysed to witness the extent it has on generator dispatch. The BAU scenario is simulated with the predicted carbon price in 2020, €17 per tonne and also the current price, €5.17 per tonne.[5] The effect from the carbon price difference is shown in table 5.3. The quantity of coal and gas generation in both scenarios is the main point to be taken from the table. Coal has a far larger share of system generation with a lower carbon price and displaces gas generation.

Fuel Type	**€5.17 per tonne**	**€17 per tonne**
Gas	10,507	17,641
Oil	0	10
Coal	8,500	2,308
Peat	741	608
Distillate	0	3

Table 5.3: Fossil fuel generation in the BAU scenario with different carbon dioxide prices

Electricity system analysis summary

This chapter analyses the effects of additional demand from increasing heat pump capacity in the heat sector has on the All-island electricity system. An overview is given in figure 5.1, introducing some of the fundamental characteristics and aspects of the system. Overall the effects shown from the NR scenario are negligible. For the MAX scenario however, a 6% increase in the electricity demand results in various effects across the system. For example, a direct result of additional demand is increased generation from energy intensive but high CO_2 emitting fuels such as coal. An additional 1.3 million tonnes of CO_2 is released from the extra fossil fuel offtake (391ktoe) necessary to meet system demand in the MAX scenario. This leads to an 8% higher CO_2 emission intensity for the entire system. Although an interesting feature of the extra demand is that ramp intensity decreases - there is less megawatts of ramping per minute with the extra demand. This is explained through the number of units started which experiences a 12% rise. These last two sentences when brought together conclude that more plants are starting up in the MAX scenario but ramp at a lower rate.

In terms of the economics drawbacks of the different scenarios, the NR scenario again has negligible impacts whereas the MAX scenario increases the total generation cost by €117 million in 2020. A 10% increase in the total system generation that causes increased emissions, emissions intensity, and increased SMP by 3%, but the extra demand also lowers ramping intensity on fossil fuel plant which is directly related to increased plant failure. Other things to account for are the effects elsewhere in macro-scale Ireland, the heat sector for example is rewarded with nearly 2 million less tonnes of non-ETS emissions, 4.6% more RES-H and a more sustainable energy system for Ireland.

[5] This 'current' price was taken on May 24th from [Invest.com, 2013]

Discussion & Concluding Remarks 6

The subject for this thesis is born out of vision. Vision in terms of looking to the future and understanding that change now, can aid ones future self. The focus of this case study Ireland is on a positive trajectory in relation to meeting the 2020 renewable electricity target, although in most other categories the nation is behind. Using this situation and moving forward with a more holistic approach could prove beneficial for the wider energy sector rather than just the electricity sector. Issues with fulfilling RES-H target has Ireland on a path to being a non-compliant member state. This report seeks to address the challenge through policy change, then analysing the system for any follow-on effects. The following research question is identified as the main focus of this report based on the problem formulation seen in chapter 1.

'What are the effects on the All-island electricity system if Ireland increases policy support for heat pumps in an attempt to fulfil their 2020 RES-H targets?'

This case study looks at heat pumps as a method for integrating the heat and electricity sectors. Using heat pumps for example; a bridge is created between both sectors to transfer energy and emissions but also to create opportunity. This paper finds that renewable energy is gained by the heat sector and non-ETS emissions are lowered, but the entire energy system gains opportunity. The opportunity to move forward to the next level of energy system integration and flexibility, based upon the concept of a holistic approach and more 'energy' focused policy rather than the current sector specific focus.

Based upon varied levels of heat pump uptake, scenarios are created in chapter 4. These scenarios identify the business-as-usual and maximum uptake levels initially, then the implementation of a policy change based on night-rate electricity is created. The analysis of the heat sector highlighted some barriers to overcome before confidence in the technology would increase. These barriers were approached using a method from Unruh which was outlined in chapter 2 called 'Continuity'. The policy proposal is in relation to changing the price of electricity used for renewable heat sources, i.e. heat pumps. This regulation change is seen as an adjustment to status quo, thus can be thought of as continuity or a continuation of the norm with minimal structural differences. This approach shows potential in terms of instilling confidence in the technology while costing a relatively small amount in the bigger picture. This proposal and the analysis thereafter starts to answer the hypotheses laid out in the theoretical approach by critically analysing the policy proposal. In terms of governmental institutional lock-in the main issue is the lack of top level buy-in into the renewable heat sector. There are little or no incentives to promote RES-H and with continued capital expenditure subsidies for oil boilers under the Energy Efficiency measures this does not look to change. This answers both the second half of the first hypothesis and the second hypothesis in terms of lock-in and the lack of evident to show any active organisational change or lowering of barriers. Change is needed to give alternatives a chance to gain market share, the concept of choice awareness is the key benefit from policy support, giving choice back to the consumer. Although the potential for change could be in existence with the Governments recent launch of a green paper on Energy, however no further updates are given on targets or expected outcomes so to assume this will lower barriers would be incorrect at this stage.

Once the scenarios are chosen and profiles created using a detailed process outlined in section 4.2, the analysis moves on to the electricity system in Ireland. From the outset, of the three scenarios selected the MAX scenario was always going to push the system the most. Straight away the effects from the MAX scenario came to fruition when an extra 2.6TWh was added to the demand. The main effects were in terms of fuel used and emissions released which were in the range of 391 ktoe extra fuel used and 1.3 million tonnes of CO_2 released. Certain aspects of the system also changed such as ramping intensities, number of hours online per start and number of start-ups for example. Even in the MAX scenario which includes an extra 6% in system demand, the majority of these differences are negligible. The fact that ramping intensity decreases, even marginally, highlights that there are no extra stress or strain on the system, actually the opposite. This shows the physical effects of the alternative scenarios on the system, the following paragraph outlines the economic effects.

The financial fallout of the proposed policy change is €12 million, the NR scenario costs are directly related to loss of revenue due to the lower electricity price. The cost is not calculated for the MAX scenario because it is not based on a policy proposal, it is only an exercise to outline the maximum uptake the heat model could see occurring in Ireland up to 2020. For the electricity sector the policy proposal induces a €4 million increase in overall total generation costs. Section 6.1 brings together the pros and cons from the proposed policy change and summarises the effects in a concise manner to close off this report.

6.1 Concluding Remarks

As explained in the previous paragraph, there are some financial losses due to the policy change proposed, and there are some added physical or technical effects of the system. More hours online and high online capacity factors should not be seen as failures but successes, why have generation capacity idle if there is a greater good to come from generating. This report uses a policy proposal to test this operational strategy. Benefits are seen through increased renewable heat, decreases in overall emissions (the savings from the non-ETS and gains in the ETS sectors are accounted for) and lower ramping intensity (if only slightly). The real question is; does additional renewable generation and lower emissions outweigh the increases in finance? or does the cost outweigh the benefit? This paper puts the idea out there for discussion. Using Ireland as a case study on increasing policy support for heat pumps in an attempt to reach the renewable targets set out in the Directive. The template is outlined in this report, one that can be used in a wide range of systems.

6.2 Further Work

The following are examples of further work that could stem from the research carried out in this report. These are followed by a short insight into the authors thoughts on the underlying issue that this report has been based upon.

- More detailed sensitivity on controlling the heat demand, for instance incorporating thermal storage into the heat demand profiles or accounting for various levels of energy efficiencies in the housing stock.
- Further analysis on the interconnection to the GB, creating different scenarios to ascertain the likelihood of Ireland one day being a net export of electricity for example or at least to gain parity in the area.

Authors thoughts

Recently the author of this paper attended a workshop on Energy System Integration in the Danish Technical University[1]. This workshop revealed plans and perspective on the future of energy and how system integration is key to moving forward. Phrases such as 'holistic', 'integration', 'demand side management', 'market dynamics', 'policy not technology is the barrier' were all mentioned time and time again, one speaker in particular quoted from a book called 'The March of the Folly'[Tuchman, 1985]:

"...the pursuit of policy in the face of happiness" - Barbara W. Tuchman

This quote, one feels is core to many of the issues at hand. A simple example of this is the 'not on my backdoor' attitude in relation to things like power plants, landfills, or wind turbines. The separation of policy from all else could be seen as the first hurdle to overcome in policy change.

[1] The workshop was part of the International Institute for Energy System Integration held on May 27th and 28th

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Appendices 7

7.1 Appendix A: Consumer Choice Heat Model Assumptions

All information on the consumer chice heat model originates from the model user handbook [Elementenergy, 2012a]. The consumer choice heat model calculates the for each technology the number of installations for each of the 35 consumer types. The primary function of the consumer choice model is to calculate the market shares for each technology type for each year in the model by following two steps. First, the total utility (attractiveness) of each technology type by combining the characteristics for each technology with the consumer preferences from the choice data. Second the market share for each technology based on its utility.

The technology attributes are combined with the consumer preference data to calculate the overall utility of each technology. Each attribute is multiplied by its respective coefficient and summed. Figure 7.1 details the interaction. Where U_n is the total utility if the specified technology n, and beta$_{0}$, $_{1}$, $_{2}$, $_{3}$ are the consumer coefficients for the different attributes. The coefficients vary between the different consumer groups (domestic, commercial and industrial) and are responsible for the variations in uptake seen in different consumer groups. As table 7.1 shows domestic consumers have a higher weighting factor for on-going savings than the industrial consumers, causing them to respond more favourably to technologies with lower payback periods.

$$U_n = \beta_0(Capex_n + Hidden\ Cost_n) + \beta_1 fuel\ cost_n + \beta_2 Maintenance_n + \beta_3\ Ongoing\ Policy\ Support_n$$

Figure 7.1: Formula for calculating the overall utility of a technology in the heat model.

The technology utilities calculated above are used in a logit model to derive the market shares for each technology in the model. A logit model allocates market share to each technology in proportion to its utility. The market shares of different technologies can be calculated by using the following logit formula, see figure 7.2.

$$Market\ Share\ of\ Technology_n = \frac{\exp(U_n)}{\sum_n^N \exp(U_n)}$$

Figure 7.2: Formula for market share for each technology

The market share of technology 'n' is expressed as a percentage of the total utility available across all technology choices. As existing heating technologies reach the end of its useful life consumers have the choice to replace the technology with the same technology type or move to a new option. The decision making frequency is based on an average boiler lifetime of 15 years, based on historic sales patterns. This corresponds to a turnover rate of 6.67% - each year 6.67% of the heating technology stock is replaced. This decision making frequency represents a limit to the amount of new technology that may be installed each year in the existing building stock. In addition to the decision makers who have replace retired boilers; the number of new buildings in a given year is added to calculate the total number of decision makers in each year for each consumer group. Only oil, gas or direct electric heating are retired each year in the model. The new renewable technologies installed in recent years will still be within their useful life by 2020 and it is assumed that these will not be retired ahead of time.

While calculating the market shares, suitability factors are also taken into account to describe the appropriateness of a given technology in a particular application. If a given technology is not suitable for a proportion of a given consumer group the number of decision makers who cannot install boilers is calculated. This option is then excluded from the logit calculation represented in figure 7.2. In some cases the uptake of a given technology can be limited by supply side constraints such as the lack of trained installers or available materials. The model includes a facility to incorporate this aspect where evidence of supply side constraints exist for a given technology type. If the total demand for a constrained technology is greater than the maximum number of sales allowed then total sales are adjusted such that the actual number of installations never exceeds the maximum number of sales allowed.

Consumer coefficients

Consumer coefficients are a central input in the choice calculation performed by the model. Coefficients applied to consumers in the residential sector are based on UK survey data collect as part of a study entitled 'The growth potential for micro-generation in England, Wales and Scotland'[Elementenergy, 2008]. For the non-domestic sector the key coefficients were derived from willingness to pay curves also use in previous studies for renewable heat uptake[Elementenergy and NERA, 2011]. Willingness to pay contains similar information on the relative value placed by consumers on upfront costs versus ongoing savings.

These coefficients are a central assumption in forecasting the uptake of renewable heat under alternative polices. There is a level of uncertainty in setting appropriate values to best represent the attitudes and decision making process of consumers in Ireland. The unavailability of similar consumer attitude survey data in Ireland means the underlying assumption is that Irish consumers have similar attitudes to their UK counterparts.

Consumer types

Ireland's heat demand is approximately 60TWh annually. The demand across each sector is met by heat generated from a number of fuel sources. The model uses various data sources to describe the nature of the heat demand across each sector by dividing the heat market into the various consumer types. Based on the 2011 census of population the number of residential dwellings in Ireland is around 2 million. 294,202 of these are vacant, meaning that the number of occupied dwellings that require heating is around 1.7 million. The GeoDirectory states that the total number of buildings stands at 1,889,143 of which 96,445 buildings are for commercial use only. The total number of industrial enterprises in Ireland is 5,028. This number does not necessarily map to a number of buildings as one enterprise of industrial scale may include several buildings. To develop a detailed picture of the nature of this demand, a survey of the sector to develop the detailed data is required. The simplifying assumption is made that each large industrial site has one large heating boiler to heat all buildings within the site. This could overstate economies of scale in some cases.

A distinct number of consumer types are modelled to represent the building stock. The computational limits of an excel model sets a ceiling on the number of consumer types that can be included in the uptake modelling. The need to define the detail of the heat market must be balanced with these computational practicalities. The detail within the available data sets also places limits on the market resolution that can be modelled.

Domestic sector

The Building Energy Rating (BER) database includes over 250,000 records of energy ratings carried out on residential properties in Ireland. This data set includes details of the age, type, floor area and energy performance asset rating of the building as well as information of the fuel types used for supplying the heating demand. The BER sample set was scaled to the population level using data available from the central statistics office. Average floor areas for each dwelling type and age are based on analysis of the BER database.

By combining the floor area and the BER data estimates of the total primary energy demand were obtained. Non-thermal demands were removed from the total based on estimated electricity consumption per dwelling for lighting and ventilation based on SEAI's 2008 publication 'Energy in the Residential Sector' [SEAI, 2013c]. A scaling factor based on data from a SEAI analysis of before and after energy efficiency upgrades and how actual consumption related to BER rating was used to calibrate the demands for energy rating categories that tend to deviate from the BER and floor area prediction. The primary energy is transformed into final thermal demand based on assumptions on the average efficiency of oil and gas boilers of 80%.

On the basis of the magnitude of the estimated thermal demands per dwelling, the dwellings were classified as follows; Small – Flat/Apartment, Medium – Terraced houses, Large – Semi-detached/Detached houses. In addition, the following energy demand categories we defined based on the outcome of the BER profiling; Low – BER B classes and above, Medium – Moderate – BER C & D classes, Large – High – BER E, F & G classes.

The BER data allowed an estimation of the proportion of dwellings that use a particular fuel type within each size band. To limit the number of consumers it was assumed that consumers in each size category are represented by two of the three available fuel options from oil, gas and electricity. The table below shows the breakdown of dwellings by counterfactual fuel type and building size.

These counterfactuals are adjusted to account for other fuel sources to match to the 2011 energy balance. This provides a starting point for 2012 and as counterfactual technologies are retired in the model consumers can choose to replace them with new renewable technologies or to reinstate the counterfactual option.

Consumer Number	Building Type	Demand Band	Counter-Factual Fuel	Thermal Demand per Building (MWh/yr)	No. of Buildings in ROI	Total Thermal Demand (GWh/yr)	Total Fuel Demand (GWh/yr)
1	small	low	NG	3.5	10,222	35.8	45
2	small	low	Electricity	3.5	13,520	47.3	48
3	large	low	NG	7.1	37,175	264.4	330
4	large	low	Oil	7.1	88,358	628.4	786
5	medium	low	NG	4.6	17,243	79.2	99
6	medium	low	Oil	4.6	10,902	50.1	63
7	small	moderate	NG	7.3	39,973	293.2	367
8	small	moderate	Electricity	7.3	52,872	387.9	396
9	large	moderate	NG	14.5	229,391	3,320.7	4,151
10	large	moderate	Oil	14.5	545,219	7,892.6	9,866
11	medium	moderate	NG	9.7	104,637	1,010.8	1,263
12	medium	moderate	Oil	9.7	66,157	639.1	799
13	small	high	NG	12.3	28,842	353.7	442
14	small	high	Electricity	12.3	38,149	467.9	477
15	large	high	NG	26.3	95,718	2,514	3,142
16	large	high	Oil	26.3	227,504	5,975.2	7,469
17	medium	high	NG	18.8	63,771	1,196.3	1,495
18	medium	high	Oil	18.8	40,320	756.4	945
		Total:			1,709,973	25,913	32,184

Table 7.1: Residential consumer types – existing buildings

Residential new builds

In addition to existing consumer types in domestic, commercial and industrial sectors, three consumer types were defined to represent new dwellings in the small, medium and large categories. These have relatively low thermal demand due to the tight requirements on thermal integrity from the 2008 building regulations. Part L of the regulations require these new dwellings to have a source of renewable heating or electricity generation. In the case of heating this requirement is 10kWh/m^2/yr and this model assumes all new dwelling choose the renewable heat option. Projections for new builds are based on the output of the 2012 national energy forecasts, rising from the current low rate of less than 10,000 units per year to over 30,000 by 2020.

Commercial sector

Compared to the residential sector, the commercial sector building stock has much less available data. The building stock analysis used in the model uses a number of sources to construct a profile of the sector. SEAI data from grant schemes, public sector programmes and the large industry network were examined. Based on the GeoDirectory data, there are 96,445 commercial only buildings in Ireland. The available commercial heat databases cover only 1% of the entire sector. Energy end-use database provides energy demands in the commercial sector by fuel type and sub-sector but is limited to information at entity-level only. This information was supplemented with data from the UK on typical building sizes and fossil fuel demand per building type was collected. Based on these typical building sizes, sub-sectors in the commercial sector were allocated to three building size groups. See figure 7.2 for details.

	Small	**Medium**	**Large**
	Offices	Wholesale	Hotels/Catering
	Retail	Public Admin	Health/Social
Sub-sectors		Education	
		Sports/Culture	
		Transport Support	

Table 7.2: Building size allocation based on activity

Combining building size and fuel demand per m^2 values, thresholds were defined for sub sectors. It is assumed that for a building defined as 'small' the maximum fuel demand is 52MWh/yr. For instance, if fuel demand for a retail company is bigger than 52 MWh/yr it is assumed that the company owns more than one retail space. See figure 7.3 for details.

Building Type	**Fuel Demand (kWh/m^2)**	**Maximum Floor Space per Building (m^2)**	**Maximum fuel demand per building (MWh/yr)**
Small	174	300	52
Medium	386	1,000	386
Large	386	3,000	1,157

Table 7.3: Energy thresholds for sub-sectors

These values where then used as thresholds for specific sub-sectors in order to convert enterprise-level data from the commercial heat databases into building-level data. Building specific data from SEAI programmes in Ireland were used to calibrate the demand thresholds. A total of six consumer types were defined. See figure 7.4 for details.

Consumer Number	**Building Type**	**Counter-Factual Fuel**	**Thermal Demand per Building (MWh/yr)**	**No. of Buildings in ROI**	**Total Thermal Demand (GWh/yr)**	**Total Fuel Demand (GWh/yr)**
19	small	NG	41.1	41.1	1,467.6	1,834
20	small	Electricity	50.3	50.3	2,245.8	2,292
21	medium	NG	286.9	286.9	1,942.7	2,428
22	medium	Oil	286.9	286.9	891.9	1,115
23	large	NG	774.2	774.2	1,365.8	1,708
24	large	Oil	774.2	774.2	1,337.9	1,672
		Total:		93,719	9,251	11,049

Table 7.4: Commercial consumer types

Industrial sector

The CSO show that there are around 5,000 industrial enterprises in Ireland. The majority of these sites are in the manufacturing sector and the SEAI SME database provides energy consumption data for over 400 sites in the manufacturing sector. In addition, the Large Industry Network (LEIN) database has details of energy consumption for 120 very large industrial sites. The data from the SME database was assumed to be representative of the industrial sector as a whole. Buildings were allocated into four categories based on their thermal demands. Average thermal demands for each building were then estimated. The assumption that industrial consumers making decisions on heating systems have a choice of one of two options – oil or gas – was imposed to limit the number of consumers in the model. Overall eight industrial consumer types were identified to represent the sector. See figure 7.5 for details.

Consumer Number	Building Type	Counter-Factual Fuel	Thermal Demand per Building (MWh/yr)	No. of Buildings in ROI	Total Thermal Demand (GWh/yr)	Total Fuel Demand (GWh/yr)
25	small	NG	288	1,034	297.8	372
26	small	Oil	288	1,920	553	691
27	medium	NG	2,000	621	1,242	1,552
28	medium	Oil	2,000	809	1,618	2,022
29	large	NG	12,000	396	4,752	5,940
30	large	Oil	12,000	226	2,712	3,390
31	very large	NG	120,000	11	1,320	1,650
32	very large	Oil	120,000	12	1,440	1,800
		Total:		5,029	13,935	17,418

Table 7.5: Industrial consumer types

Technology

Technology cost and performance data is based on a number of data sources. SEAI grant schemes have details on the costs of domestic level technologies which is supplemented by UK and international data. These include 'Review of technical information on renewable heat technologies, AEA for DECC (2011), the potential costs of DH networks (Póyry for DECC (2009)) and 'Achieving deployment of renewable heat, Element Energy and NEARA for the committee on Climate Change' [Elementenergy and NERA, 2011]

Figure 7.3 shows the summary detail of the technology costs, including the estimates for hidden and missing costs. Hidden and missing costs represent additional real and perceived costs to consumers installing heating systems. These costs are set by consumer and technology and are taken from previous research for SEAI by Element Energy. Costs include project identification, research, scoping and negotiating, obtaining planning permission, construction management, cost of disruption, hassle cost of fuel deliveries and hassle costs of additional works. Upper and lower limits are estimated for these allowing some sensitivity analysis in the modelling.

Sector	Size	Fuel	Average thermal demands per building (MWh/yr)	Total number of buildings in Ireland	Capex (€/kW)	Opex excluding fuel (€/kW)	Efficiency	Load factor	Indicative size (kWth)	Lifetime (years)	CF hidden cost Low (Euro/installation)	CF hidden cost High (Euro/installation)
Domestic	Small	*Oil*	7.96	165,417	327.27	9.00	90%	8%	11	15	43	132
		Gas	8.04	209,250	272.73	9.00	90%	8%	11	15	43	132
		Electricity	6.55	66,392	220.00	2.20	100%	9%	8	15	0	0
		Biomass	8.04	-	1,090.91	13.64	85%	8%	11	20	60	1,849
		Solar	1.82	-	1,800.00	21.00	-	8%	3	20	60	212
		AS & GS HP	8.04	-	1,500.00	8.33	250%	10%	9	20	60	212
	Large	*Oil*	17.99	813,043	225.00	9.00	90%	13%	16	15	43	132
		Gas	17.68	417,722	187.50	9.00	90%	13%	16	15	43	132
		Electricity	12.26	38,149	220.00	2.20	100%	10%	14	15	0	0
		Biomass	17.68	-	800.00	9.38	85%	13%	16	20	60	1,849
		Solar	1.82	-	1,800.00	21.00	-	8%	3	20	60	212
		AS & GS HP	17.68	-	1,071.43	5.36	250%	14%	14	20	60	212
Commercial	Small	*Oil*	286.87	3,109	86.40	3.00	91%	22%	150	15	456	1,175
		Gas	80.25	42,494	72.00	3.00	91%	22%	42	15	456	1,175
		Electricity	50.33	44,625	235.00	1.70	100%	19%	30	15	0	0
		Biomass	80.25	-	450.00	18.00	81%	22%	42	15	1,247	4,870
		Solar	19.62	-	1,650.00	9.00	-	7%	32	15	687	1,870
		AS & GS HP	80.25	-	600.00	15.12	350%	22%	42	15	447	1,270
	Large	*Oil*	774.24	1,728	86.40	3.00	91%	20%	450	15	456	1,175
		Gas	774.24	1,764	72.00	3.00	91%	20%	450	15	456	1,175
		Electricity	-	-	-	-	-	-	-	-	-	-
		Biomass	774.24	-	450.00	18.00	81%	20%	450	15	1,247	4,870
		Solar	19.62	-	1,650.00	9.00	-	7%	32	15	687	1,870
		AS & GS HP	774.24	-	600.00	15.12	350%	21%	420	15	447	1,270
Industrial	Small	*Oil*	795.51	2,729	86.40	0.50	90%	65%	140	15	1,690	8,588
		Gas	930.39	1,655	72.00	0.50	90%	66%	160	15	1,840	10,388
		Biomass	930.39	-	450.00	35.00	81%	66%	160	15	1,247	4,870
	Large	Oil	17,445.38	238	50.00	0.50	90%	66%	3,000	15	1,690	8,588
		Gas	14,918.92	407	65.00	0.50	90%	68%	2,500	15	1,840	10,388
		Biomass	14,918.92	-	425.00	35.00	81%	68%	2,500	15	12,743	125,693

Figure 7.3: Summary of technology costs used in the modelling

Consumer choice heat model - fuel prices

Figure 7.4 illustrates the fuel prices used up to and including 2020 in the BAU scenario. The coloured cells are the values which are changed in the alternative scenarios.

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Domestic	Electricity	€175	€184	€200	€202	€205	€209	€212	€216	€220	€224	€228
	Gas	€49	€52	€60	€61	€62	€64	€65	€67	€68	€70	€71
	Oil	€76	€85	€87	€87	€87	€89	€91	€93	€95	€97	€99
	Biomass (chips)	€34	€34	€35	€39	€40	€41	€43	€44	€46	€47	€46
	Biomass (pellets)	€46	€47	€49	€55	€55	€56	€56	€57	€53	€57	€51
Residential	Electricity	€157	€166	€180	€183	€185	€188	€192	€195	€198	€202	€206
	Gas	€42	€45	€49	€50	€51	€53	€54	€55	€56	€58	€59
	Oil	€54	€65	€65	€66	€66	€67	€69	€70	€72	€73	€75
	Biomass (chips)	€34	€34	€40	€34	€36	€37	€38	€40	€41	€42	€41
	Biomass (pellets)	€39	€41	€45	€49	€50	€50	€50	€51	€47	€51	€46
Industrial	Electricity	€117	€119	€129	€131	€132	€135	€137	€139	€142	€144	€147
	Gas	€31	€38	€39	€40	€41	€42	€43	€44	€45	€46	€47
	Oil	€44	€54	€54	€54	€55	€56	€57	€58	€59	€61	€62
	Biomass (chips)	€34	€34	€40	€34	€36	€37	€38	€40	€41	€42	€41
	Biomass (pellets)	€39	€41	€45	€49	€50	€50	€50	€51	€47	€51	€46

Figure 7.4: Fuel prices used for business-as-usual scenario in the heat model

7.2 Appendix B: Model Calibration - 2012 All-Island Electricity Model

The purpose of 2012 model is to provide a close representation of the 2012 electricity system for calibration purposes. The output from model simulations are compared with actual generation data from the market operator to determine how closely the model mimics what occurred in 2012. Additional complexity is incrementally added to determine the impact of operational constraints and reserve requirements on the economic dispatch. The output from an economic dispatch model, a constrained dispatch model, an operational reserves model and a model with both constraints and reserve requirements is compared to the actual 2012 dispatch[1] by fuel type and technology.

An economic dispatch model takes the information on the cost of generating electricity and the technical capabilities from each unit on the system and dispatches the least cost arrangement of these to meet demand. Real time systems must deal with network constraints while providing operating reserve to protect the system stability against unexpected events. Network constraints and operating reserve requires can be added to the economic dispatch model to mimic a real time system. The addition of these adds to the computational complexity of the model resulting in longer solution times. Figure 7.5 shows how the output of the models compared to the annual metered output recorded in 2012.

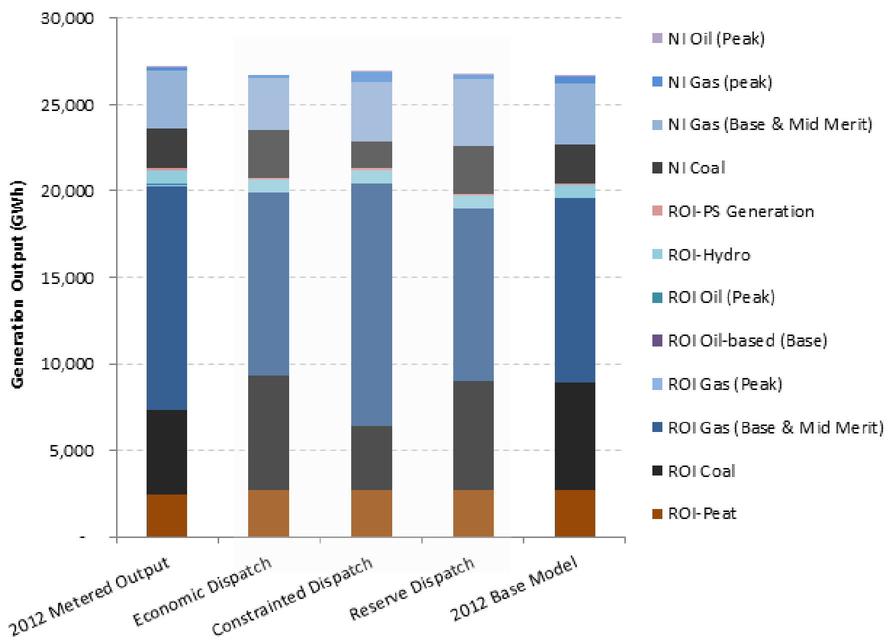

Figure 7.5: 2012 Metered generation compared across model calibration steps

The economic dispatch represents the least cost arrangement of generators to meet demand in the ROI and NI based on the economic merit order of the generation units and their technical characteristics. As the lowest cost generation source coal generation is maximised running at high levels of available capacity. Peat receives support through the PSO to help the economics of the fuel source within the market and generates when available. Gas CCGT and mid-merit units make up the largest proportion of generation but the cost of generation means that this generation tends to be turned down at times of low net load.

[1] Metered generation for each generator is available from the Market Operator, see [Single Energy Market Operator, 2013]

The addition of constraints alters the generation shares with gas generation increasing and coal decreasing the ROI. Coal generation increases, displacing gas in NI, due to the requirement for one or both units in Kilroot to be online when demand is at certain levels. A number of the constraints related to network congestion are driving the change. The requirement to have a number of units online in Dublin at all times increases gas generation. The increase is mitigated by the requirement for the gas generators in the Cork region to run at a reduced output due to network congestion in the area. ROI coal is also displaced by the higher running duty in the Dublin units. The requirement for at least one of the coal units in NI to run when system load is above a certain threshold sees significantly more output from these units.

The provision of primary, secondary and tertiary reserve is optimised to meet the requirements at least cost. Units providing reserve reduce output below maximum capacity (or load point) by an amount that covers the reserve risk requirement. The cost of providing reserve represents the opportunity cost of reducing output plus any additional costs imposed through reserve providing units operating at lower efficiencies. The higher cost gas units have a lower opportunity cost and tend to provide the majority of the primary and secondary reserve requirements. Fast starting peaking plant is the most expensive units on the system and tends to provide much of the tertiary reserve. Gas generation reduces as a result of the output being reduced to provide shorter response reserve. Hydro units tend to have a limited amount of generation output available in a given day. As a result hydro generation tends to be dispatch to meet demand at times of high generation costs. During other periods through the day the potential hydro energy acts as a reserve resource.

Comparing aggregated annual data may overstate accuracy as dispatch differences maybe averaged out across the year – i.e. differences early in the year maybe cancelled out by differences in the opposite direction late in the year. When the model dispatches generation is relevant to assessing the representativeness of the simulation to the actual generation in 2012. The variation of modelled dispatch is assessed across fuel and technology categories against the actual half hourly metered generation. The Normalised Mean Absolute Error (NMAE) can allow for the accuracy of the modelled dispatch at high time resolutions. NMAE looks at the average deviation of the modelled dispatch from the recorded half hourly data as a proportion of installed capacity. Table 7.6 shows the NMAE for different categories of generation.

These counterfactuals are adjusted to account for other fuel sources to match to the 2011 energy balance. This provides a starting point for 2012 and as counterfactual technologies are retired in the model consumers can choose to replace them with new renewable technologies or to reinstate the counterfactual option.

Normalised MAE Variation (%)				
	Economic Dispatch	**Constrained Dispatch**	**Reserve Dispatch**	**Full Model**
ROI Gas (Peak)	3%	3%	3%	3%
ROI Gas (Base & Mid Merit)	10%	8%	11%	9%
ROI Coal	25%	29%	21%	19%
ROI Oil (Mid Merit)	0%	0%	1%	2%
ROI Oil (Peak)	1%	1%	1%	1%
ROI-Peat	11%	11%	11%	11%
ROI-Hydro	20%	20%	20%	20%
ROI-PS Generation	8%	19%	16%	16%
NI Gas (Peak)	22%	47%	26%	34%
NI Gas (Base & Mid Merit)	7%	12%	8%	8%
NI Coal	21%	32%	18%	18%
NI Oil (Peak)	1%	1%	1%	1%

Table 7.6: Normalised Mean Absolute Error (NMAE) model calibration half hourly dispatch compared to 2012 metered generation.